DOCUMENT RESUME

ED 370 681 PS 022 327

AUTHOR Wakai, Kunio, Ed.
TITLE Research and Clinical Center for Child Development Annual Report, 1992-1993, No. 16.
INSTITUTION Hokkaido Univ., Sapporo (Japan). Faculty of Education.
REPORT NO ISSN-0386-8435
PUB DATE 30 Mar 94
NOTE 153p.; For 1991-1992 Annual Report, see ED 363 392.
PUB TYPE Collected Works - General (020)

EDRS PRICE MF01/PC07 Plus Postage.
DESCRIPTORS Acoustic Phonetics; Biology; *Child Development; Children; Developmental Disabilities; Exploratory Behavior; Eye Hand Coordination; Foreign Countries; Handedness; Mental Retardation; Motor Development; Muscular Strength; Parent Child Relationship; Scientific Literacy; Sentence Structure
IDENTIFIERS Maternal Speech; Reaching Behavior; Walking

ABSTRACT

A variety of topics on human development is covered in this annual report. The 11 articles are: (1) "Young Children's Personifying and Vitalistic Biology" (Kayoko Inagaki and Giyoo Hatano); (2) "Acoustic Analysis of Natural Maternal Speech to Preschool Language Impaired and Normal Children" (Debora L. Scheffel and Murray Alpert); (3) "Comprehension, Imitation, and Production of Simple Sentences in Mentally Retarded Individuals" (Toshiharu Matsumoto and Takashi Furutsuka); (4) "Early Intervention for Children with Developmental Disorders with Emphasis on Their Relationship with the Caregivers" (Takashi Furutsuka and Yuki Tanaka); (5) "On the Developmental Origin of Human Handedness" (Brian Hopkins); (6) "Dynamics of Self-Organization in Human Locomotion" (Richard E. A. van Emmerik and Richard C. Wagenaar); (7) "A Natural Physical Perspective on the Development of Infant Eye-hand Coordination: A Search for the Laws of Control" (Geert J. P. Savelsbergh and John van der Kamp); (8) "Development of Coordination of Spontaneous Leg Movements" (Julliette Vaal and others); (9) "The Role of Strength in the Development of Reaching" (Lia Out and Geert J. P. Savelsbergh); (10) "Are There Phase Transitions in the Development of Eye-hand Coordination?" (Raymond H. Wimmers and others); and (11) "Exploring Exploration in the Development of Action" (John van der Kamp and Geert J. P. Savelsbergh). References are included with each article. (TJQ)

****
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
****

ED 370 681

U.S. DEPARTMENT OF EDUCATION
Office of Educational Research and Improvement
EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)

X This document has been reproduced as received from the person or organization originating it.

☐ Minor changes have been made to improve reproduction quality.

• Points of view or opinions stated in this document do not necessarily represent official OERI position or policy.

PS 022327

PERMISSION TO REPRODUCE THIS MATERIAL HAS BEEN GRANTED BY

Kunio Wakai

TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC).

BEST COPY AVAILABLE

FACULTY OF EDUCATION
HOKKAIDO UNIVERSITY
Sapporo Japan

RESEARCH AND CLINICAL CENTER FOR CHILD DEVELOPMENT

Annual Report
1992-1993
No. 16

March 1994
Editor: Kunio Wakai
Co-editor: Chen Shing-jen

CONTENTS

Young Children's Personifying and Vitalistic Biology 1
Kayoko Inagaki and Giyoo Hatano

Acoustic Analysis of Natural Maternal Speech to Preschool Language Impaired and Normal Children 27
Debora L. Scheffel and Murray Alpert

Comprehension, Imitation, and Production of Simple Sentences in Mentally Retarded Individuals 39
Toshiharu Matsumoto and Takashi Furutsuka

Early Intervention for Children with Developmental Disorders with Emphasis on Their Relationship with the Caregivers 51
Takashi Furutsuka and Yuki Tanaka

On the Developmental Origin of Human Handedness 63
Brian Hopkins

Dynamics of Self Organization in Human Locomotion 81
Richard E. A. van Emmerik and Richard C. Wagenaar

A Natural Physical Perspective on the Development of Infant Eye-hand Coordination: A Search for the Laws of Control 103
Geert J. P. Savelsbergh and John van der Kamp

Development of Coordination of Spontaneous Leg Movements 111
Juliëtte Vaal, Knoek van Soest and Brian Hopkins

The Role of Strength in the Development of Reaching 119
Lia Out and Geert J. P. Savelsbergh

Are There Phase Transitions in the Development of Eye-hand Coordination? 123
Raymond. H. Wimmers, Geert J. P. Savelsbergh, Peter J. Beek and Brian Hopkins

Exploring Exploration in the Development of Action 131
John van der Kamp and Geert J. P. Savelsbergh

Hokudai RCCCD Roster 139

目　次

幼児の擬人的・生気論的生物学 …… 1
稲垣佳世子・波多野誼余夫

言語障害幼児と健常児に対する母親の話し言葉の音響学的分析 …… 27
デボラ・シェッフェル

精神発達遅滞者における単純な文の理解，模倣および産出 …… 39
松本　敏治

発達障害児への早期介入：介護者との関係を中心として …… 51
古塚　孝

利き手の発達的起源について …… 63
ブライアン・ホプキンス

移動行動の自己体制化のダイナミックス …… 81
リチャルド・ヴァン・エマリック，リチャルド・ワーヘンナル

乳児における目と手の協応の発達に関する自然物理学的視点：制御法則の探求 ……103
ヒールット J. P. サフェルスベルハ，ジョン・ヴァン・デル・カンプ

自発的脚運動の協応の発達 ……111
ジュリエット・ヴァール，カヌーク・ヴァン・ズウスト，
ブライアン・ホプキンス

手伸し行動の発達における強度の役割 ……119
リア・アウト，ヒールット J. P. サフェルスベルハ

目と手の協応の発達に位相の移行はあるか？ ……123
レーモンド・ウィッマー，ヒールット J. P. サフェルスベルハ，
ベータ・ベーク，ブライアン・ホプキンス

動作の発達における探索行動の役割 ……131
ジョン・ヴァン・デル・カンプ，ヒールット J. P. サフェルスベルハ

北大RCCCD関係者一覧 ……139

YOUNG CHILDREN'S PERSONIFYING AND VITALISTIC BIOLOGY[1]

Kayoko Inagaki
Chiba University
Giyoo Hatano
Dokkyo University

This article aimed at investigating the nature of young children's naive biology by reviewing a large number of studies conducted in our laboratories. More specifically, we tried in the first part of the article to answer the following two critical questions: What components does children's knowledge system for biological phenomena have before being taught systematically at school? Can the knowledge system be called naive biology? We proposed that young children's biological knowledge system has at least three components, that is, knowledge needed to specify the target objects or phenomena of biology, constrained analogies with knowledge about humans or other familiar animals as the source for inferring attributes or behaviors of biological kinds, and a vitalistic causal explanatory framework, and that these three constitute a form of biology. In the last part, we were concerned with the use, acquisition, and change of this naive biology. We claimed that it is readily used and is functional in children's lives, that its core is acquired based on specific cognitive constraints as well as the general mechanism of personification and the resultant vitalistic causality but it is differently instantiated and elaborated through activity-based experiences and shared beliefs and artifacts in the surrounding culture, and that it evolves into intuitive biology educated lay adults possess as its weaknesses are overcome by learning of school or scientific biology.

Young Children's Personifying and Vitalistic Biology

There has been a debate in recent years as to whether young children have acquired a form of biology. On the one hand, Carey (1985) claimed that children before around age 10 make predictions and explanations for biological phenomena based on intuitive psychology (i.e. intentional causality). According to her, young children lack the mind-body distinction, more specifically, do not recognize that our bodily functions are independent of our intention nor that biological processes which produce growth or death are autonomous. On the other hand, a number of recent studies have suggested that children possess biological knowledge at much earlier ages than Carey has claimed. Some developmentalists (e.g., Hatano & Inagaki, 1987) have asserted that the differentiation between psychology and biology occurs, if it does, much earlier than Carey (1985) assumed. Others have proposed that biological phenomena are con-

[1] This is an expanded and modified version of our paper, "Young children's naive theory of biology" by Hatano and Inagaki, to appear in *Cognition*, 1994, 50.

ceptualized differently from other phenomena from the beginning (e.g., Keil, 1992).

However, it should be noted that there are more agreements than disagreements among major investigators of young children's understanding of biological phenomena. All of them agree that young children possess "theories" (or cognitive entities equivalent to them) about biological phenomena, more specifically, concerning internal processes involved in the individual survival and reproduction of animals and plants, and their external behaviors and properties relevant to these processes. Here the term "theory" means a coherent body of knowledge that involves causal explanatory understanding. In other words, it is assumed that young children's bodies of knowledge about biological phenomena have something more than a collection of facts and/or procedures to obtain desired results (Kuhn, 1989). It is obvious that this conceptualization is a distinct departure from the Piagetian position, which assumed young children to be preoperational and thus incapable of offering more or less plausible explanations in any domain.

At the same time, however, none of the investigators have ever claimed that young children have acquired the modern science of biology. As Carey (1985) aptly put it, they are "totally ignorant of the physiological mechanisms involved" (p. 45). They know that input (e.g., eating too much) is related to output (becoming fat or upsetting the stomach), but nothing about what mediates them at physiological and/or biochemical levels. The debatable issue is whether they possess a version of endogenous biology, similar to ethnobiology or folkbiology, which is separated from psychology.

This paper is divided into two parts. In the first part, based on a large number of studies conducted in our laboratories, we will specify the contents of young children's theory like knowledge system for biological phenomena, that is, what components are included in it. We will show that young children own three essential components that constitute a form of biology. In the last part, also by reviewing our experimental studies, we will be concerned with the use, acquisition, and change of young children's naive biology. Research on these issues has been scant, partly because it presupposes some specification of the contents of naive biology. We hope to further elucidate the nature of young children's biology, by presenting our empirical findings on these issues.

Components of Young Children's Biological Knowledge

We are convinced that the body of knowledge which young children possess about biological phenomena (e.g., behavior of animals and plants needed for individual survival; bodily process; reproduction and inheritance of properties to offsprings) has at least three components, and believe that these three constitute a naive biology (Inagaki, 1993b). The first is knowledge enabling one to specify objects to which biology is applicable; in other words, knowledge about the living nonliving distinction, and also about the mind-body distinction. The second is a mode of inference which can produce consistent and reasonable predictions for attributes or behaviors of biological kinds. The third is a non-intentional causal explanatory framework for behaviors needed for individual survival and bodily processes.

Knowledge Needed to Specify Targets of Biology

Animate-inanimate distinction. An increasing number of recent studies have revealed that young children have the animate-inanimate distinction. Let us take a few examples. Gelman, Spelke, and Meck (1983) asked such questions as "Does X have a property of Y?" or "Can X do Y?" to children aged 3 to 5 years, using typical animates (i.e., a person and a cat) and inanimates (i.e., a rock and a doll or puppet) as targets. Four types of animate properties were used there: actions (e.g., walk, see), body parts (e.g., a mouth, a head), reciprocal actions (e.g., you talk to X/X talks to you) and mental-emotional states (e.g., think, feel sad). The results indicated that 3 year-olds as well as 4- and 5-year olds made correct responses to questions for each of the four types of properties of each target object at about 90 percent or more of the time, and to questions for a person at 100 percent of the time. This illustrates that children aged 3 to 5 have not only rich knowledge about people but also knowledge needed to distinguish animate entities from inanimate ones.

Massey and Gelman (1988), using unfamiliar animate entities as target objects, found that preschool children can distinguish animals and inanimate objects in terms of whether they have a capacity for self initiated movements or not. That is, 3- and 4-year olds were shown photographs of unfamiliar objects, including mammals, non-mammalian animals, statues with familiar animal like forms and parts, wheeled vehicles, and multipart rigid objects, and asked whether each of these objects could go up and down a hill by itself. These children were correct on about 85% of their first yes-no answers, indicating that they answered animals could go up and down a hill by themselves, while inanimate objects, even if they looked like animals, couldn't. This result was corroborated by analyses of children's individual patterns of responses; a great majority of them showed a pattern of responses which was best described by the rule, or its variant, that all animals can move by themselves and that all of the inanimate objects require an external agent in order to move. Analyses of explanations that the children gave spontaneously or in request for justifications of their yes-no responses suggested that these children tended to change the kind of their explanations depending upon the type of the object. When talking about animals, children often focused on parts that enable the target to move, such as, "It can move because it has feet," or referred to some general feature of the target's appearance, such as, "It's an animal because it has a face." For inanimate objects, such as wheeled vehicles or rigid objects, they also referred to parts enabling movement, such as, "It can roll down on its wheels," or to an agent needed to move the object, saying, "It needs a push and then it goes," or "You have to carry it down."

Based on these results, Gelman (1990) proposed a hypothesis that young children at their early ages possess skeltal principles focusing on "causal mechanism" enabling objects to move. In other words, these principles, which focus attention on those natural kinds that move on their own, the innards principle, and which draw attention to objects that do not move on their own, the external-agent principle, lead one to rapidly acquire knowledge about the animate-inanimate distinction. Gelman claims that the experimental evidence on the inside-outside of the object supported her hypothesis.

Most previous studies on the animate-inanimate distinction have concerned the

distinction between animals and non living things, typically represented by the studies described above, and only a small number of studies have dealt with plants as living things. Studies concerning the animate inanimate distinction in terms of whether the target object was alive provided the evidence that young children had difficulty in acknowledging that plants are alive (e.g., Richards & Siegler, 1984, 1986; Stevy & Wax, 1989). For example, Richards and Siegler (1984) reported that less than 20 percent of children aged 4 to 5 and only a half of children aged 6 to 7 showed the "living things" rule that humans, non human animals and plants are alive, while non-living things are not. However, the term, "alive," for young children might not map that for adults (Carey, 1985), because it is ambiguous in a sense that it is used in varied ways (including metapholical usages) in everyday life. In fact, Massey & Gelman (1988) found that the children who correctly judged whether each object could go up and down the hill failed in judging whether each was alive in considerable degree.

More recent studies examined, using more specific indicators other than the life status, whether young children recognize plants as distinct from nonliving things, and indicated that they can do so in some respects. For example, Inagaki (1993a) found that children before age 6 distinguish plants and animals from nonliving things in terms of growth, i.e., changes in size as time goes by. This study was an extension of Rosengren, Gelman, Kalish and McCormick (1991) which investigated children's differentiation between animals and artifacts in terms of growth; children of ages 4 to 6 were presented with a picture of a flower's sprout (or a new artifact or a young animal) as the standard stimulus picture, and were then asked to choose which of two other pictures would represent the same plant (or artifact or animal) a few hours later and several months/years later. Figure 1 shows an example of stimulus and choice cards for each of plants, artifacts and animals. As indicated in Figure 2, the children showed "invariance" patterns (i.e., no change in size both a few hours later and several months/years later for all the items) for artifacts but "growth" patterns (i.e., changes in size either/both a few hours later or/and several months/years later) for plants and animals. Backscheider, Shatz, and Gelman (1993) also reported that 4-year olds recognize that, when damaged, both animals and plants can regrow, whereas artifacts can be mended only by human intervention.

That young children treat inanimate things differently from animals and plants is not sufficient for claiming that they have an integrated category of living things. Proof that they are aware of the commonalities between animals and plants is needed. By asking 5- and 6-year-olds whether a few examples of plants or those of inanimate things would show similar phenomena to those we observe for animals, Hatano and Inagaki (1994) found that a great majority of them recognized commonalities between animals and plants in terms of feeding and growing in size over time, and thus distinguished them from inanimate things. Moreover, many of them justified their responses by mapping food for animals to water for plants, such as "A tulip or a pine tree dies if we do not water it". For growing in size, a substantial number of the children offerred a phenomenon of plants' getting bigger from a seed or a bud; there found children who referred to watering as corresponding to feeding as a condition for growth. For growth in number by reproduction, in addition, about a half of the children recognized

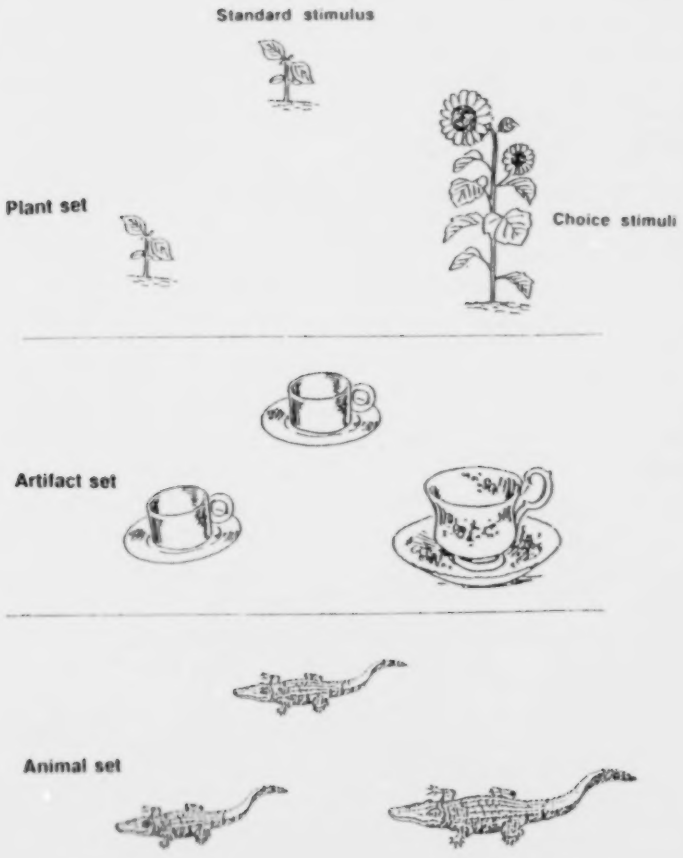


FIGURE 1 An example set of standard stimulus and choice stimulus cards for plants, artifacts, and animals.

the similarity between animals and plants, and a substantial number of them justified their responses by referring to seeds as similar to animals' increase by having babies or eggs, indicating that buds come out from seeds buried in the ground and grow in number (or produce many flowers); there also found children who seemed to regard plants' having flowers after flowers or becoming thickly covered by leaves as a similar phenomenon.

Springer and Keil (1991) indicated that preschoolers differentiated plants (and animals) from artifacts in terms of causal mechanisms involved in color transmission; they preferred natural biological mechanisms in color transmission for a flower and a dog, whereas they chose non-biological mechanical explanations for cans as plausible. Based on these and other related studies, we can conclude that children are able to acquire the living-nonliving distinction by age 6.

Mind-body distinction. Can young children distinguish between the body and the mind? Though studies dealing with this issue are small in number yet, the available

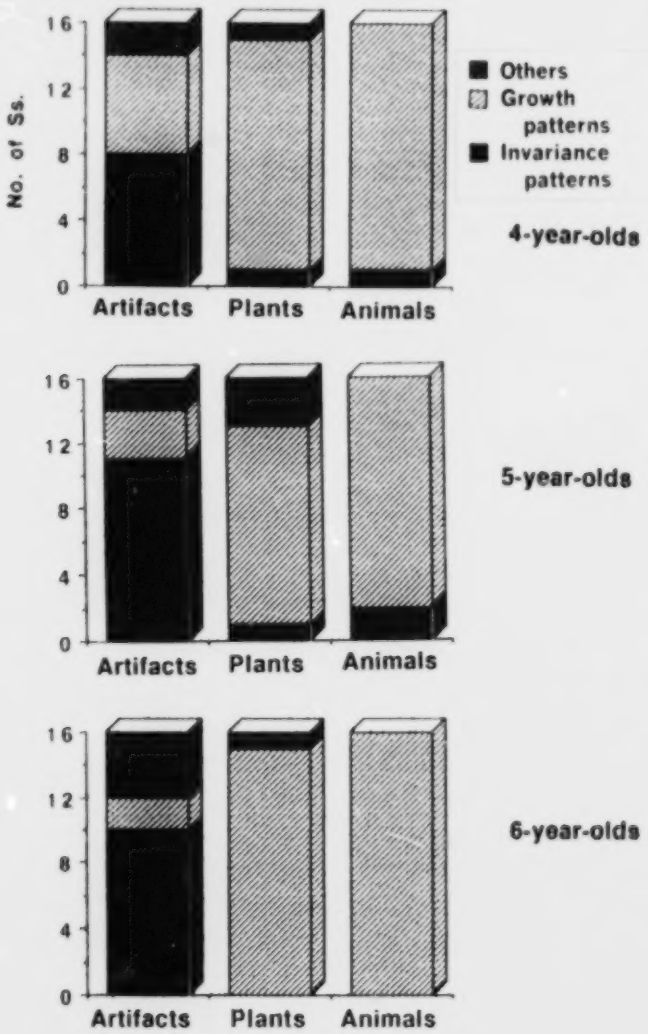


FIGURE 2 Distributions of three patterns for artifacts, plants and animals in each age group

data show that the answer is Yes. That is, young children distinguish functions of body from those of mind, in other words, biological phenomena from social or psychological ones, both of which are observed among a subset of animate things. Springer and Keil (1989) reported that children of ages 4–7 consider those features leading to biologically functional consequences for animals to be inherited, while other sorts of features, such as those leading to social or psychological consequences, to be not. Here children listened to descriptions about two abnormal features that animal parents had, and then were asked whether the baby would be born with those features in normal or abnormal form. The result indicated that the children considered characteris-

tics leading to biologically functional consequences (e.g., a white stomach inside so they could eat a lot and stay strong) as inherited, and those leading to social or psychological consequences (e.g., a white stomach inside that made them feel angry a lot) as non-inherited. Siegal (1988) reported that children of ages 4-8 recognize that illness is caused not by moral but by medical factors; they have substantial knowledge of contagion and contamination as causes of illness. Inagaki and Hatano (1987) revealed that children of 5-6 years of age recognize that the growth of living things is beyond their intentional control. For example, a baby rabbit grows not because its owner wants it to but because it takes food. These findings all suggest that young children recognize the autonomous nature of biological processes.

An even more systematic study on the mind-body distinction was reported by Inagaki and Hatano (1993, Experiment 1). By interviewing children using a variety of questions, they showed that even children aged 4 and 5 already recognize not only the differential modifiability among characteristics that are unmodifiable by any means (e.g., gender), that are bodily and modifiable by exercise or diet (e.g., running speed), and that are mental and modifiable by will or monitoring (e.g., forgetfulness), but also the independence of activities of bodily organs (e.g., heartbeat) from a person's intention. Figure 3 shows the children's responses to the controllability of activities of bodily organs.

Another important piece of evidence for this distinction is young children's use of non-intentional (or vitalistic) causality for bodily phenomena but not for social-psychological ones; this point is discussed in a later section.

Personification as Means to Make Educated Guesses about Living Things

When children do not have enough knowledge about a target animate object, they can make an educated guess by using personification or the person analogy in a constrained way. Young children are so familiar with humans that they can use their

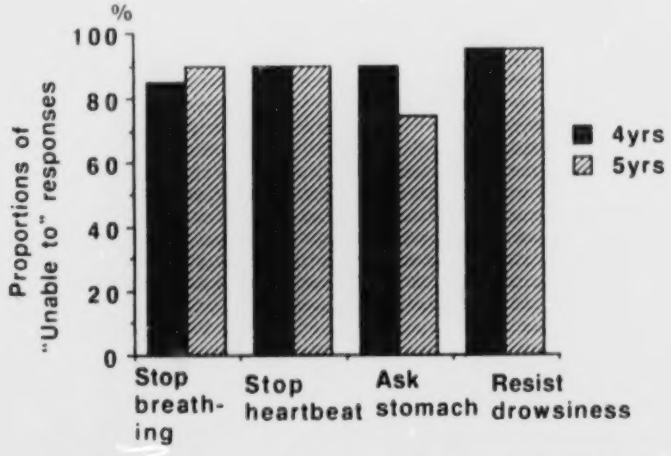


FIGURE 3 Children's responses to the controllability of activities of internal organs.

knowledge about humans as a source for analogically attributing properties to less familiar animate objects or predicting the reactions of such objects to novel situations, but they do not use knowledge about humans indiscriminately. In other words, they can use personification or person analogy in an adaptive way in that they generate answers without committing many overpersonifying errors. How is it possible for young children who have not acquired an articulated taxonomy of properties (e.g., all-living thing properties, animal properties, etc.) to do so? They seem to be helped by two constraints when they transfer knowledge about humans to other animate objects.

One is a differential application or similarity constraint, which requires the target object to be more or less similar to a human in order for the person analogy to be applied to it. As Vosniadou (1989) insists, children tend to apply an analogy on the basis of salient similarity between the target and the source, though the "depth" of this perceived similarity varies with the richness and structuredness of the knowledge base children have. Generally, the closer the target object is biologically to a human being, the more often children recognize its similarity and thus apply the person analogy. In fact, some studies have found that young children attribute human characteristics to targets in proportion to the extent that they are perceived similar to people (Carey, 1985; Inagaki & Sugiyama, 1988).

The other constraint in young children's person analogy is a factual check or feasibility constraint that Inagaki and Hatano (1987) proposed. This requires that the predicted behavior of the target object through the person analogy be feasible, and that, if not, the prediction be rejected. They claimed that this constraint works after the person analogy is attempted, that is, one examines whether the analogical inference is tenable on the basis of factual knowledge about the target object. Even young children often know specific facts about "observable attributes" of an animate object, e.g., whether or not it has a mouth, walks, speaks to humans, etc. (e.g., Gelman, Spelke & Meck, 1983; Inagaki & Hatano, 1987). Thus they may use this knowledge to check the plausibility of predictions reached by the person analogy, even though the knowledge is not powerful enough to generate predictions in itself. Inagaki and Hatano (1987, 1991) provided evidence supporting this idea on the role of feasibility constraint in a process of personification.

In one of their studies (Inagaki & Hatano, 1991), children of age 6 were asked to predict a grasshopper's or tulip's reactions to three types of novel situations: (a) similar situations, in which a human being and the target object would behave similarly, and thus the person analogy generates predictions plausible to them in light of their specific kowledge, (b) contradictory situations, where the target object and a human would react differently, and predictions based on the person analogy contradict children's specific knowledge about the target, and (c) compatible situations, where the object and a human being would in fact react differently, but predictions obtained through the person analogy do not seem implausible to them. Example questions for each situation are as follows: "We usually feed a grasshopper once or twice a day when we raise it at home. What will happen with it if we feed it 10 times a day?" [In the case of a tulip, the word *water* was used instead of *feed*.] (a similar situation); "Suppose a woman buys a grasshopper. On her way home she drops in at a store with

this caged grasshopper. After shopping she is about to leave the store without the grasshopper. What will the grasshopper do?" (contradictory); "Does a grasshopper feel something if the person who has been taking care of it daily dies? [If the subject's answer is "Yes"] How does it feel?" (compatible).

Results indicated that for the similar situations many of the children generated reasonable predictions with some explanations by using person analogies, whereas they did not give personified predictions for the contradictory situations. As expected, they produced unreasonable predictions for the compatible situations, where they were unable to check the plausibility of products of person analogies because of the lack of adequate knowledge (e.g., about the relation between the brain and feeling).

What follows are example responses of two children for the grasshopper questions and for the tulip questions, respectively:

M.K. (6 years, 3 months): For the "too much eating" question of the similar situation, "The grasshopper will be dizzy and die, 'cause the grasshopper, though it is an insect, is like a person (in this point)"; for the "left behind" question of the contradictory situation, "The grasshopper will be picked up by someone, 'cause it cannot open the cage." [*"If someone does not pick up the cage, what will the grasshopper do?"*] "The grasshopper will just stay there." [*"Why doesn't the grasshopper do anything? Why does it just stay there?"*] "It cannot (go out of the cage and) walk, unlike a person"; for the caretaker's death question of the compatible situation, "The grasshopper will feel unhappy."

Y.S. (6 years, 0 months): For the too much eating question in the similar situation, "The tulip will go bad. [*why?*] If we water the tulip too much, it cannot drink the water so much, so it will wither"; for the left behind question in the contradictory situation, "The tulip doesn't speak. . . . Someone will bring the (potted) tulip to the police office, as a lost thing." [*"If there is no one who does such a thing, what will the tulip do? Is there anything the tulip can do?"*] "The tulip cannot move, because it has no feet"; for the caretaker's death question in the compatible situation, "The tulip will surely be sad. It cannot say 'sad,' but it will feel so inside."

These illustrate well how these children applied knowledge about humans differentially according to the types of situations. Generally speaking, children generate reasonable predictions, using person analogies in a constrained way, and the person analogy may be misleading only where they lack (biological) knowledge to check analogy-based predictions.

Young children's frequent use of personification is not limited to biological inference, but is observed in other behavioral domains. However, it is a very useful tool in biological inference, because humans are a species of advanced animals, and they have a body and reveal biological phenomena like other animals.

Non-intentional Causality

The experimental evidence presented so far enables us to indicate that young children have a coherently organized body of knowledge applicable to living things. This body of knowledge can be called a theory only when a causal explanatory framework is included in it. This concerns the third component of their biological knowledge. Here the type of causality, intentional or non-intentional, determines the nature of a theory. Carey (1985) claimed that, as mentioned above, children before age 10

base their explanations of biological phenomena on an intentional causality, because they are ignorant of physiological mechanisms involved. On the contrary, we claim that young children before schooling can apply a non-intentional causality in explaining biological phenomena, and thus they have a form of biology which is differentiated from psychology.

Young children cannot give articulated mechanical explanations when asked to explain biological phenomena (e.g., bodily processes mediating input-output relations) in an open-ended interview (e.g., Gellert, 1962); sometimes they try to explain them using the language of person-intentional causality (Carey, 1985). These findings apparently support the claim that young children do not yet have biology as an autonomous domain. It seems inevitable to accept this claim so long as we assume only two types of causalities, i.e., intentional causality versus mechanical causality, as represented by Carey (1985). However, we propose an intermediate form of causality between these two. Children may not be willing to use intentional causality for biological phenomena but not as yet able to use mechanical causality. These children may rely on this intermediate form of causality, which might be called "vitalistic causality."

Intentional causality means that a person's intention causes the target phenomenon, whereas mechanical causality means that physiological mechanisms cause the target phenomenon. For instance, a specific bodily system enables a person, irrespective of his or her intention, to exchange substances with its environment or to carry them to and from bodily parts. In contrast, vitalistic causality indicates that the target phenomenon is caused by activity of an internal organ, which has, like a living thing, "agency" (i.e., a tendency to initiate and sustain behaviors). The activity is often described as a transmission or exchange of the "vital force," which can be conceptualized as unspecified substance, energy, or information. Vitalistic causality is clearly different from person-intentional causality in the sense that the organ's activities inducing the phenomenon are independent of the intention of the person who possesses the organ.

In Inagaki and Hatano (1990) some of the children of ages 5–8 gave explanations referring to something like vital force as a mediator when given novel questions about bodily processes, such as, what the halt of blood circulation would cause; for example, one child said, "If blood does not come to the hands, they will die, because the blood does not carry energies to them," and another child, "We wouldn't be able to move our hands, because energies fade away if blood does not come there." However, as the number of these children was small, we did another experiment to induce children to choose a plausible explanation out of the presented ones.

Inagaki and Hatano (1993, Experiment 2) predicted that even if young children could not apply mechanical causality, and if they could not generate vitalistic causal explanations for themselves, they would prefer vitalistic explanations to intentional ones for bodily processes when asked to choose one from among several possibilities. We asked 6-year-olds, 8-year-olds, and college students as subjects to choose one from three possible explanations each for six biological phenomena, such as blood circulation and breathing. The three explanations represented intentional, vitalistic and mechanical causality, respectively.

An example question on blood circulation with three alternative explanations was as follows: Why do we take in air? (a) Because we want to feel good [intentional]; (b) Because our chest takes in vital power from the air [vitalistic]; (c) Because the lungs take in oxygen and change it into useless carbon dioxide [mechanical].

As shown in Figure 4, the 6-year-olds chose vitalistic explanations as most plausible most often; they chose them 54% of the time. With increasing age the subjects came to choose mechanical explanations most often. It should be noted that the 6-year-olds applied non-intentional (vitalistic plus mechanical) causalities 75% of the time, though they were more apt to adopt intentional causality than the 8-year-olds or adults.

This vitalistic causality is probably derived from a general mechanism of personification. One who has no means for observing the opaque inside or details of the target object often tries to understand it in a global fashion, by assuming it or its components to be human-like (Ohmori, 1985). Hence, young children try to understand the workings of internal bodily organs by regarding them as human-like (but non-communicative) agents, and by assigning their activities global life-sustaining characters, which results in vitalistic causality for bodily processes. We can see a similar mode of explanation in the Japanese endogenous science before the Meiji restoration (and the beginning of her rapid modernization), which had evolved with medicine and agriculture as its core (Hatano & Inagaki, 1987).

Young children seem to rely on vitalistic causality only for biological phenomena. They seldom attribute social psychological behavior, which is optional and not needed for survival, to the agency of a bodily organ or part, as revealed by Inagaki and Hatano (1993, Experiments 3 and 3a). The following is an example question for such behavior used in the study: "When a pretty girl entered the room, Taro came near her. Why did he do so?" Eighty percent of the 6-year-olds chose, "Because Taro wanted to become a friend of hers" [intentional explanation], whereas only 20 percent opted for, "Because Taro's heart urged him to go near her" [vitalistic]. For biological phenomenon questions, almost the same as those used in Experiment 2 of Inagaki and Hatano (1993) except for excluding the mechanical causal explanation, they tended to choose vitalistic explanations rather than intentional ones.

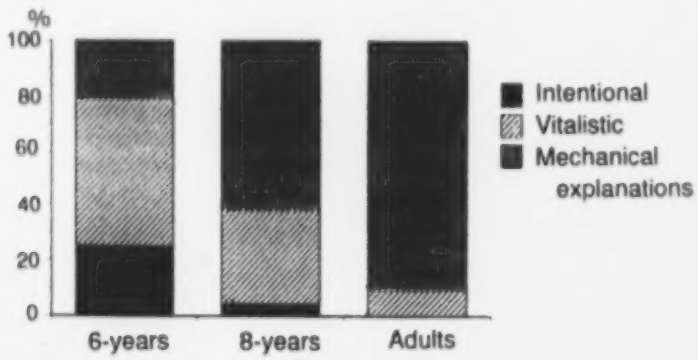


FIGURE 4 Percentages of choices for different types of causal explanations.

Then, two theoritical issues emerge. First, does the use of vitalistic causality by young children falsify Carey's claim? It does not do so necessarily. We do not know yet which of human properties, in addition to "agency", children assign to bodily organs. It is possible that children, especially younger ones, find organ-intentional vitalistic explanations appealing for biological phenomena. If this is the case, we must conclude that young children's biology is still "psychological" in the sense that it involves intentional states, though the domain is differentiated from psychology. Second, what is the relationship between the vitalistic explanation for biological phenomena and the teleological-functional explanation for biological properties (Keil, 1992)? Both are certainly in-between the intentional and the mechanical; both seem to afford valid perspectives of the biological world. One interpretation is that they are essentially the same idea with different emphases—the teleological concerns more the why or the cause, whereas the vitalistic is concerned more with the how or the process. Another interpretation is that, because the vitalistic explanation refers to activity of the responsible organ or bodily part (implicitly for sustaining life), it is closer to mechanical causality than is the teleological one, which refers only to the necessity. Anyway, it will be intriguing to examine these characterizations of young children's "biological" explanations in concrete experimental studies.

Young Children Possess a Naive Theory of Biology

From the above findings we can conlude that children as young as 6 years of age possess three essential components of biology, that is, the living-nonliving and the mind-body distinctions, a mode of inference enabling one to produce consistent and reasonable predictions for animate objects, and a non-intentional causal explanatory framework. These components correspond respectively to the three features that Wellman (1990) lists in characterizing framework theories: ontological distinctions, coherence, and a causal-explanatory framework. We can conclude that, contrary to Carey (1985), children before schooling have acquired a form of biology differentiated from psychology.

Use, Acquisition and Change of Naive Biology

How Naive Biology is Used

The components of young children's biology, which are described in the preceding section, have been identified through interviews, more specifically, based on children's answers to experimental questions regarding biological phenomena. In this sense their naive biology is psychologically real. However, some skeptical readers may wonder if such answers are generated by strange experimental questions, and if children almost never use such "biological knowledge" in their everyday life. In order to persuade those readers, we will discuss in this section (1) whether naive biology is relied on in children's everyday problem solving and understanding, and (2) whether it enhances children's learning and memory about animals and plants.

Children's use of naive biology in their daily life. Although we have not yet examined systematically a database of young children's utterances, a few observant early educators have reported instances revealing that naive biology enables young chil-

dren to make sense of biological phenomena they observe, and also to solve daily problems involving animals and plants. For example, Motoyoshi (1979) reports the following statement of a 5-year-old girl. Based on accumulated experience with raising flowers, and relying on her naive biology, she concluded: "Flowers are like people. If flowers eat nothing (are not watered), they will fall down of hunger. If they eat too much (are watered too often), they will be taken ill". This superb analogy demonstrates that young children's personifying biology can serve as the basis for understanding botanical phenomena and thus constitute what Keil (1992) calls a mode of construal.

Likewise, we believe that young children's biology is useful in everyday biological problem solving, more specifically, in (a) making predictions for reactions of familiar animate entities to novel situations, (b) finding a cause for an unusual reaction of animals and plants, and (c) predicting properties and behaviors of unfamiliar entities. An anecdotal but impressive example of causal attribution for an animal's unusual physical reaction is reported also by Motoyoshi (1979). Children aged 5 in a day care center inferred that, when they observed unusual excretion of a rabbit they were taking care of every day, it might be suffering from diarrhea like a person, and after group discussion, they produced an idea of making the rabbit take medicine for diarrhea as a suffering person would.

Hatano and Inagaki (1991b) examined experimentally whether young children would make causal reasoning based on their personifying biology, as suggested in the above example. They presented to 6-year-olds three bodily phenomena of a squirrel, which can also be observed for humans (being constipated, diarrhea, and getting older and weaker), and asked them to guess a cause for each phenomenon. About three quarters of them on the average could offer some reasonable causes, and also judge the plausibility of causes suggested by the experimenter. About a half of them explicitly referred to humans at least once in their causal attributions for a squirrel. At the same time, however, some of their expressions strongly suggest that they edited or adapted to this animal those responses obtained by the person analogy (e.g., "A squirrel became weaker because it did not eat chestnuts"). Naive biology seems to provide young children with a conceptual tool for causal reasoning about bodily phenomena of other animals as well as humans.

Naive biology as prior knowledge for learning about animals and plants. We expect that young children promptly remember those facts concerning animals and plants which are plausible within their naive biological framework. In our experiment in progress, we presented 5- and 6-year-olds one of the two lists, connected or random, and asked to remember sentences in it. Each sentence consisted of an unfamiliar animal as the subject, its behavior, and outcome. In the connected list, the behavior and the outcome were causally connected in naive biology, because the cause induces the outcome in humans (e.g., "A coyote ate rotten meat and had diarrhea"). In the random list, causes and outcomes were randomly paired. The data are being analyzed, but we expect to find that young children would recall sentences in the connected list much better, even when sentences were false for those animals.

Naive biology is particularly useful because it helps children learn meaningfully

procedures for taking care of animals and plants as well as themselves in everyday life. Global understanding of internal bodily functions is enough for such purposes. Inagaki and Kasetani (1994) examined whether inducing the person analogy, a critical component of naive biological knowledge, would enhance 5- and 6-year-olds' comprehension of raising procedures of a squirrel. The subjects were aurally given the description of the procedures while watching pictures visualizing them. The description included several references to humans in the experimental condition but not in the control condition. For example, about the necessity of giving a variety of food to a squirrel, the experimenter indicated, "You do not eat favorite food only. You eat a variety of food, don't you?" After listening to the description of all procedures, the children were asked to tell how to raise a squirrel to another lady (a confederate). They were asked questions by this lady, e.g., "What kind of food might I give a squirrel? Favorite chestnuts only, chestnuts, seeds and vegetables mixed, or ice cream?" They were thus required to choose an alternative and to give the reason.

The experimental group children, irrespective of age, gave more often adequate reasons for their correct choices than the control ones, though their superiority in the number of correct choices was significant only for the younger subjects. For instance, one 5-year-old child said, "Don't feed chestnuts only. You must give a squirrel a plenty of seeds and carrots, because a person will die if he eats the same kind of food only, and so will it."

There have also been studies suggesting that children can find how to solve a problem by being given some hints to use knowledge about humans when they are at a loss. In Inagaki and Hatano's (1987) study on analogy mentioned above, children who had no idea about reactions of the target objects in novel situations were given a hint, such as, "If you were in that situation, what would you do?" After making a response to this inserted question, they were again asked the same question about the target object. This hint question helped about 80% of the children produce some predictions for the target objects, and about 70% of their predictions were reasonable.

A similar example of the effect of such a hint is found in a teacher's guidebook made by a Japanese Research and Development group called the *"Kyokuchi"* method in science education (1974). In the unit on animals' bodily structures and their ways of living children are given the following problem: "Which is a bigger eater, a starfish or sea anemone?" By being given a hint, such as "Taking exercise makes you hungry, doesn't it?", they are likely to figure out the correct choice successfully.

What triggers biological knowledge. Young children's naive biology is functional partly because its components are promptly and effortlessly retrieved and used to generate more or less plausible ideas. Their personifying and vitalistic biology seems to be triggered almost automatically whenever children come into contact with novel phenomena which they recognize as "biological" (Inagaki, 1990b). Then, what phenomena are recognized by children as biological? Those occurring within a (human) body are almost always treated as biological. In addition, behaviors and properties which are relevant to survival (and also reproduction) seem to trigger children's biological knowledge. For example, in experiments by Vera and Keil (1988) those contexts referring to a person's living better or becoming more active produced more extended and accu-

rate induction of human biological properties to animals, whereas those indicating a person's subjective feelings did not. In Inagaki and Hatano's (1994) experiment contexts referring to the vital force produced induction extended even to plants.

Speaking generally, making an educated guess by applying insufficient knowledge is often rewarded in everyday life, both in individual problem solving and in social interaction, so most everyday knowledge is readily used. Children's naive biology is not an exception, we believe. In fact in our study described above (Inagaki & Hatano, 1987) it was very rare that the children gave no prediction or the "I don't know" answer to our questions which were somewhat unusual. It should also be noted that naive biological knowledge is seldom applied "mechanically." As mentioned earlier, children constrain their analogies by factual, procedural or conceptual knowledge about the target to generate a reasonable answer.

Acquisition of Naive Biology

As already mentioned, our experimental data strongly suggest that children as young as 6 years of age have acquired a form of biology. This early acquisition of biology is not surprising from the perspective of human evolution, because it has been essential for our species to have some knowledge about animals and plants as potential foods (Wellman & Gelman, 1992) and also knowledge about our bodily functions and health (Hatano, 1989; Inagaki & Hatano, 1993). When children acquire an autonomous domain of biology is still an open question for us, because we have not examined whether much younger subjects too possess a form of biology.

However, we think that the acquisition of biology comes a little later than that of physics or psychology. Infants seldom need biological knowledge, since they do not need to take care of their health nor try to find food themselves. Moreover, autonomous biology has to deal with entities which have agency (i.e., initiate and maintain activity without external forces) but can hardly communicate with us humans, and thus has to apply an intermediate form of causality between the intentional and mechanical. Autonomous biology also requires to include animals and plants, which appear so different, into an integrated category of living things. Though there is some evidence that even infants can distinguish objects having a capacity for self initiated movement from those not having it (e.g., Golinkoff, Harding, Carlson, & Sexton, 1984), this cannot directly serve as the basis for the living-nonliving distinction.

Cognitive bases of naive biology. Whether naive biology gradually emerges out of naive psychology (Carey, 1985) or is a distinct theory or mode of construal from the start (Keil, 1992) is still debatable. It is true that, as Keil argues, preschool children have some understanding of the distinction between the biological and the social-psychological (See above). In Vera and Keil (1988), for example, 4-year-olds' inductions about animals, when given the biological context, resembled those previously found for 7-year-olds, who were given the same attribution questions without context; giving the social-psychological context to 4-year-olds did not affect the inductions they made. However, young children may overestimate the controllability of bodily processes by will or intention. In fact, our modified replication study on the controllability of internal bodily functions suggests that 3-year-olds are not sure whether the workings of

bodily organs are beyond their control (Inagaki & Suzuki, 1991).

Our own speculation about how young children acquire personifying and vitalistic biology through everyday life experiences is as follows. Children notice through somatosensation that several "events", uncontrolled by their intention, are going on inside the body. Since children cannot see the inside of the body, they will try to achieve "global understanding" by personifying an organ or bodily part. Considering that young children use analogies in a selective, constrained way (Inagaki & Hatano, 1987, 1991; Vosniadou, 1989), it is plausible that they apply the person analogy to bodily organs in that way, too. More specifically, they attribute agency and some related human properties but not others (e.g., the ability to communicate) to these organs. They also through personification generalize this global understanding of the body to other living things.

A set of specific innate or very early cognitive constraints is probably another important factor in the acquisition of naive biology. It is likely that even very young children have tendencies to attribute a specific physical reaction to a specific class of events, such as that diarrhea is caused by eating something poisonous. These tendencies enhance not only their rejection of intentional causality for bodily phenomena but also their construction of more specific beliefs about bodily processes.

Universals in naive biology. That innate constraints serve as the bases for acquiring naive biology has been strongly suggested by the universality of selected aspects of folkbiology and naive biology. As suggested by Atran (1990), it may be possible to find the "common sense" or core beliefs shared by all forms of folkbiology and even by scientific biology. Although what are such core beliefs is debatable, the taxonomy of animate entities or a set of the ontological distinctions is certainly included among them, because all folkbiological classifications reported so far correspond to the scientific one highly accurately (e.g., Boster, 1991).

Likewise, much of the research inspired by Piaget, e.g., those examining children's attribution of life status and consciousness to a variety of objects, has shown parallels among the biological understanding or naive biology of children in different cultures. The distinctions between animals and terrestrial inanimate objects are particularly strong. The frequent use of personification and reliance on vitalistic causality, important components of naive biology, are also expected to be more or less universal, though they have been documented only in a few countries.

Activity based experiences. We are willing to admit that, because of the above general mechanism of personification and the resultant vitalistic causality, which "fit nicely with biology" (Keil, 1992, p. 105), and specific cognitive constraints, there must be some core elements in naive biology that are shared among individuals within and between cultures, as suggested by Atran (1990). However, we would like to emphasize that this does not mean children's activity-based experiences do not contribute to the acquisition. Some such experiences are also universal in human ways of living, but others may vary and thus produce differently instantiated versions of naive biology. For example, if children are actively engaged in raising animals, it will be possible for them to acquire a rich body of knowledge about them, and therefore to use that body of knowledge, as well as their knowledge about humans, as a source for analogical

predictions and explanations for other biological kinds.

Our studies have in fact revealed that such an activity may produce a slightly different version of naive biology from the ordinary one. Inagaki (1990a) compared the biological knowledge of kindergarteners who had actively engaged in raising goldfish for an extended period at home with that of the children of the same age who had never raised any animal. Although these two groups of children did not differ in factual knowledge about typical animals in general, the goldfish-raisers had much richer procedural, factual, and conceptual knowledge about goldfish. More interestingly, the goldfish-raisers used the knowledge about goldfish as a source for analogies in predicting reactions of an unfamiliar "aquatic" animal (i.e., a frog), one that they had never raised, and produced reasonable predictions with some explanations for it. For example, one of the raisers answered when asked whether we could keep a baby frog in the same size forever, "No, we can't, because a frog will grow bigger as goldfish grew bigger. My goldfish were small before, but now they are big." It might be added that the goldfish-raisers tended to use person analogies as well as goldfish analogies for a frog. In other words, the goldfish-raisers could use two sources for making analogical predictions.

Moreover, in another study (Kondo & Inagaki, 1991; See also Hatano & Inagaki, 1992), goldfish-raising children tended to enlarge their previously possessed narrow conception of animals. As shown in Figure 5 as an example, Goldfish-raisers attributed animal properties which are shared by humans (e.g. having a heart, excreting, etc.) not only to goldfish but also to a majority of animals phylogenetically in between humans and goldfish at a higher rate than non-raisers. This suggests that the experience of raising goldfish modifies young children's preferred mode of biological inferences.

Cultural and linguistic variables. The biological understanding observed in different cultures is not identical. The most striking of the differences thus far reported concerns ideas about plants of children in Israel. Stavy and Wax (1989) showed that about a half of a sample of 6-12 year-olds, when asked to judge the life status of animals, plants, and nonliving things, classified plants either as nonliving things or as falling within a third category, things that are neither living nor nonliving. Beliefs about inanimate objects also may differ between cultures. Whereas recent studies conducted in North America indicate that young children seldom attribute life or other living thing properties to any terrestrial inanimate objects (e.g., Dolgin & Behrend, 1984; Richards & Segler, 1984), Inagaki and Sugiyama (1988) reported that some Japanese preschoolers extended mental properties even to inanimate objects without movement or function, such as stones.

Hatano, Siegler, Richards, Inagaki, Stavy and Wax (1993) tried to differentiate between universal and culturally specific aspects of children's conceptions of life and understanding of attributes of living things, by comparing kindergarteners, 2nd-, and 4th-graders from Israel, Japan and the United States. The children were asked whether two instances each of four object types (people, other animals, plants and inanimate objects) possessed each of 16 attributes that included life status (being alive), unobservable animal attributes (e.g., has a heart), sensory attributes (e.g., feels pain), and

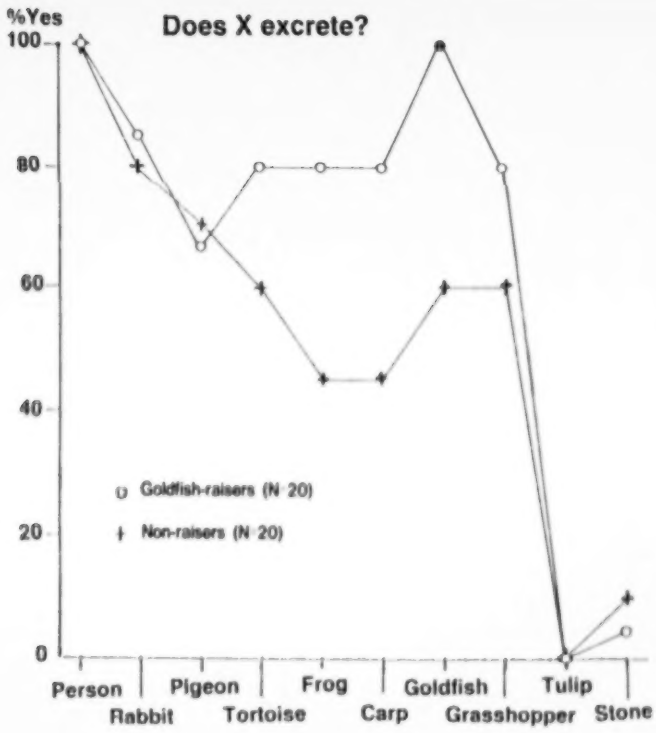


FIGURE 5 Attributional patterns of excretion to varied objects in goldfish raising and non raising children.

attributes true of all living things (e.g., grows bigger).

The results illustrate both similarities and differences across cultures in children's biological understanding. Children in all cultures knew that people, other animals, plants, and inanimate objects were different types of entities, with different properties, and were extremely accurate regarding humans, somewhat less accurate regarding other animals and inanimate objects, and least accurate regarding plants. At the same time, as predicted from cultural analyses, Israeli children were considerably more likely not to attribute to plants properties that are shared by all living things, whereas Japanese children, whose overall accuracy was comparable to the Israeli, were considerably more likely to attribute to inanimate objects properties that are unique to living things.

These differences are especially interesting because they suggest that children's naive biology is influenced by beliefs within the culture where they grow up. Consider why Japanese children might be more likely than children in the U.S. or Israel to view plants or inanimate objects as alive and having attributes of living things. Japanese culture includes a belief that plants are much like human beings. This attitude is represented by the Buddhist idea that even a tree or blade of grass has a mind. In Japanese folkpsychology, even inanimate objects are sometimes considered to have

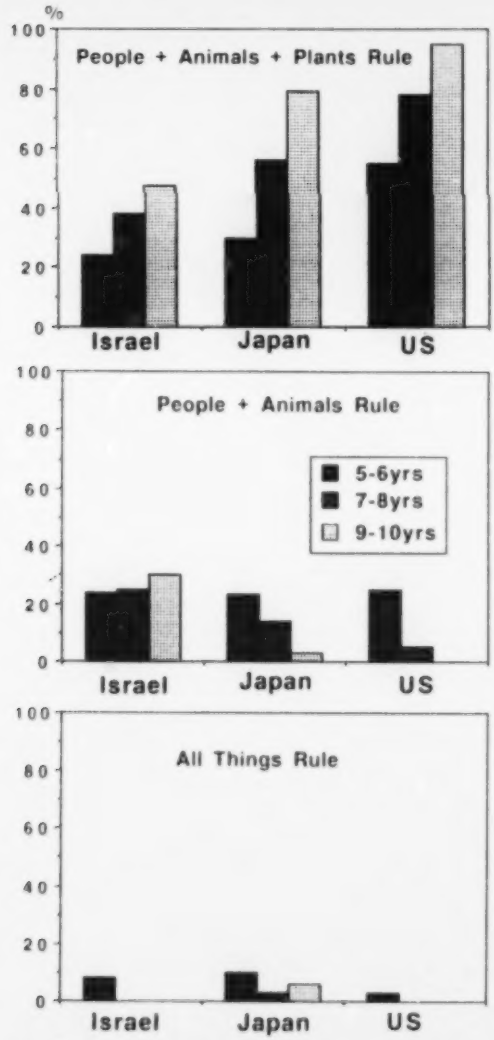


FIGURE 6 Percentages of children who adopted "people, animals and plants rule," "people and animals rule" and "all things rule."

minds. For example, it is at least not a silly idea for Japanese to assign life or divinity not only to plants but also to inanimate objects, especially big or old ones. In addition, linguistic factors seem to influence Japanese children's attributional judgments. The *kanji* (Chinese character) representing it has a prototypal meaning of "fresh" or "perishable" as well as "alive." Therefore, this kanji can be applied to cake, wine, sauce, and other perishable goods.

Similar features of culture and language may account for Israeli children being less apt than American or Japanese children to attribute to plants life status and prop-

erties of living things (See Figure 6). Stavy and Wax (1989) suggested that within the Israeli culture, plants are regarded as very different from humans and other animals in their life status. This cultural attitude parallels that of a Biblical passage (*Genesis*, 1, 30), well known to Israeli students, indicating that plants were created as food for living things including animals, bird, and insects. Adding to, or perhaps reflecting, their cultural beliefs, the Hebrew word for "animal" is very close to that for "living" and "alive." In contrast, the word for "plant" has no obvious relation to such terms.

How culture inflences the development of biological understanding has yet to be studied. Parents, schools, and mass media may serve to transmit cultural beliefs. For example, Japanese parents may communicate the attitude through their actions toward plants and divine inanimate objects, though they do not usually tell their children this explicitly. Culture may provide children with opportunities to engage in activities that lead them to construct some particular biological understanding, as in the case of children of raising goldfish (Inagaki, 1990a; Hatano & Inagaki, 1992).

Evolution into Intuitive Biology

So far we have emphasized strengths of young children's naive biology. Doesn't it have any weaknesses? Of course, it does. Its weaknesses are obvious even when compared with intuitive biology that lay adults have, which is considered as a product of interaction between naive biology and so-called scientific biology. Let us list some major weaknesses of naive biology: (a) limited factual knowledge, (b) lack of inferences based on complex, hierarchically organized biological categories, (c) lack of mechanical causality, and (d) lack of some conceptaual devices (e.g., "evolution," "photosynthesis").

As children grow older, they acquire more and more pieces of biological knowledge (elimination of the weakness a), and with it the status of humans changes. Young children regard humans as unique, and thus as a prototypical species of all living things, whereas older children and adults consider them as a very special species and as only a kind of animals.

As children grow older, their personifying and vitalistic biology gradually changes toward truly "non psychological" (if not scientific) biology by eliminating the above weaknesses (b) and (c), namely, toward a biology which relies on category-based inferences and rejects intentional causal explanations. We assume that this change (or the fundamental restructuring of knowledge) is almost universal, at least among children growing up in highly technological societies, and that it can occur without systematic instruction in biology, though schooling may have some general facilitative effects on it. Acquisition of basic conceptual devices (elimination of the weakness d) seems to be difficult to be achieved without being taught so-called scientific biology at school, and incorporating them meaningfully into children's existing body of knowledge can usually be achieved only with the restructuring of that knowledge.

Let us present a few relevant empirical studies. Johnson, Mervis and Boster (1992) found that, whereas 10 year olds and adults possess a category of primates and include a human in it, 7 year olds regard a human very difierent even from a monkey.

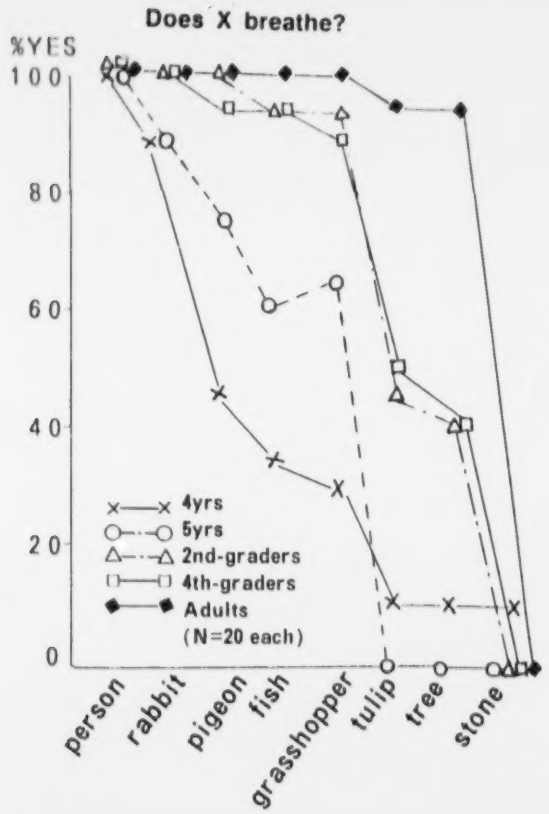


FIGURE 7 Attributional patterns of breathing to varied objects in each age group.

Carey (1985) also reported similar results, using the induction paradigm; when 4-year-olds were taught some novel properties on people, they attributed them to other animals to much greater than when taught on dogs. In contrast, 10-year-olds and adults who were taught on dogs were hardly distinguishable in attributional patterns from those taught on people. Rather, projections from dogs were slightly greater than from people. These results indicate that the status of humans changes from that of a prototype to what is not more prototypical than dogs.

Inagaki and Sugiyama (1988) examined how young children's human-centered or "similarity-based" inference would change as they grew older. They gave attribution questions, such as "Does X have a property Y?", to children aged 4 to 10 and college students. Results indicated that there was a progression from 4-year-olds' predominant reliance on similarity-based attribution (attributing human properties in proportion to perceived similarity between target objects and humans) to adults' predominant reliance on category-based attribution (attributing by relying on the higher-order category membership of the targets and category-attribute associations). Figure 7 shows an example of developmental patterns obtained in the attribution of anatomical/physiologi-

cal properties.

This shift from similarity based to category based inferences is induced not only by an increased amount of knowledge but also by the development of metacognitive beliefs evaluating more highly the usefulness of higher order categories (Inagaki, 1989). Children realize that higher order categories are more dependable than the similarities for making correct predictions. Higher order categories are very helpful in predicting unfamiliar animals' behaviors, attributes, habitats, and so on. This realization facilitates the use of such categories in any situation in which a biological inference is required. Hatano and Inagaki (1991a) provided data to confirm this idea, using a task designed to assess children's metacognitive beliefs about the dependability of category based versus similarity based inference.

As children grow older, there also occurs a developmental change in causality for internal bodily functions. In contrast to young children's vitalistic, and sometimes even intentional, biological explanations, older children reject intentional explanations for biological phenomena and are inclined to use mechanical causality exclusively. In Experiment 2 of Inagaki and Hatano's (1993) study, the difference between 6 year olds and 8 year olds was larger than the difference between 8 year olds and adults in terms of preference for mechanical explanations and avoidance of intentional ones (See Figure 4).

These results suggest that young children's biology is qualitatively different from the biology that older children and adults have, and that, in accordance with Carey's claim, there occurs a conceptual change in biological understanding between ages 4 and 10. However, contrary to her claim, this change is characterized not as the differentiation of biology from psychology but as a qualitative change within the autonomous domain of biology, because children as young as 6 years of age already possess a form of biology.

Another important change may occur as a result of the learning of scientific biology at school, which is often beyond intuitive biology. In order to be able to reason "scientifically" in biology one needs to know its basic concepts and principles, major conceptual devices which cannot be acquired without intervention. For example, if one does not know the phenomenon of photosynthesis, one will not be able to understand the difference between animals and plants (i.e., plants can produce nutriment themselves), and thus may accept the false analogy of mapping water for plants with food for animals. We assume that, unlike the first conceptual change just described above, this change is hard to achieve and thus occurs only among a limited portion of older children or adolescents.

Is adults' intuitive biology no more personifying? Does the intuitive biology no more rely on vitalistic biology? Answers for these questions are No. The fact that there exists a shift from similarity based to category based inferences does not mean that older children and adults never rely on the similarity to people in their attributions. Inagaki and Sugiyama (1988) reported that a substantial number of adults as well as older children still rely on similarity to people in attributing mental properties to varied animate entities. Morita, Inagaki and Hatano (1988), using reaction time measures, revealed that college students use the similarity to people to some extent not only for

mental properties but also anatomical physiological ones in a situation in which they have to respond very quickly and thus are not able to use the category membership of target objects and category property relationships. These results strongly suggest that personification or the person analogy may be used even by adults as a fallback strategy.

The fact that college students preferred much more strongly mechanical causality to the vitalistic one (Inagaki & Hatano, 1993, Experiment 2) does not mean that they never rely on the latter in any situation. One of the college students in Inagaki and Hatano (1993) consistently chose vitalistic explanations, and answered for an inquiry at the interview after experiment, "We usually choose those including 'oxygen' or 'the heart works like a pump' because we have learned in school to do so. However, I chose others because they were most convincing and comprehensible to me." This suggests that vitalistic biology continues to work as a basis of understanding and to be used in situation where people do not think that they are required to answer based on so called scientific biology.

Conclusions

Since Carey (1985), young children's naive biology has been an exciting topic for research in cognitive development. As more and more ambitious researchers have joined to study it, a richer database has been built and finer conceptualizations offered about this specific issue. It will probably be a popular topic for the coming several years, and research questions about naive biology, like the ones discussed so far in this article, can be better answered and/or better rephrased.

REFERENCES

Atran, S. (1990). *Cognitive foundations of natural history: Towards an anthropology of science.* Cambridge: Cambridge University Press.

Backscheider, A. G., Shatz, M. & Gelman, S. A. (1993). Preschoolers' ability to distinguish living kinds as a function of regrowth. *Child Development*, **64**, 1242-1257.

Boster, J. S. (1991). The information economy model applied to biological similarity judgment. In L. B. Resnick, J. M. Levine, & S. D. Teasley (Eds.), *Perspectives on socially shared cognition* (pp. 203-225). Washington, D.C.: American Psychological Association.

Carey, S. (1985). *Conceptual change in childhood.* Cambridge, MA: MIT Press.

Dolgin, K. G. & Behrend, D. A. (1984). Children's knowledge about animates and inanimates. *Child Development*, **55**, 1646-1650.

Gellert, E. (1962). Children's conceptions of the content and functions of the human body. *Genetic Psychology Monographs*, **65**, 291-411.

Gelman, R. (1990). First principles organize attention to and learning about relevant data: Number and the animate-inanimate distinction as examples. *Cognitive Science*, **14**, 79-106.

Gelman, R., Spelke, E. & Meck, E. (1983). What preschoolers know about animate and inanimate objects. In D. Rogers and J. A. Sloboda (Eds.), *The acquisition of symbolic skills* (pp. 297-326). New York: Plenum.

Golinkoff, R. M., Harding, C. G., Carlson, V., & Sexton, M. E. (1984). The infant's perception of causal events: the distinction between animate and inanimate objects. In L. P. Lipsitt & C. Rovee-Collier (Eds.), *Advances in Infancy Research*, (vol. 3, pp. 145-165). Norwood, NJ: Ablex.

Hatano, G. (1989). Language is not the only universal knowledge system: A view from "everyday

cognition." *Dokkyo Studies in Data Processing and Computer Science*, **7**, 69-76.

Hatano, G. & Inagaki, K. (1987). Everyday biology and school biology: How do they interact? *The Quarterly Newsletter of the Laboratory of Comparative Human Cognition*, **9**, 120-128.

Hatano, G. & Inagaki, K. (1991a). *Learning to trust higher order categories in biology instruction*. Paper presented at the meeting of the American Educational Research Association, Chicago.

Hatano, G. & Inagaki, K. (1991b). *Young children's causal reasoning through spontaneous personification*. Paper presented at the 33rd annual convention of the Japanese Association of Educational Psychology, Nagano. (in Japanese).

Hatano, G. & Inagaki, K. (1992). Desituating cognition through the construction of conceptual knowledge. In P. Light & G. Butterworth (Eds.), *Context and cognition: Ways of learning and knowing* (pp. 115-133). London: Harvester/Wheatsheaf.

Hatano, G. & Inagaki, K. (1994). *Recognizing commonalities between animals and plants*. Paper to be presented at the meeting of the American Educational Research Association, New Orleans.

Hatano, G., Siegler, R. S., Richards, D. D., Inagaki, K., Stavy, R., & Wax, N. (1993). The development of biological knowledge: A multi national study. *Cognitive Development*, **8**, 47-62.

Inagaki, K. (1989). Developmental shift in biological inference processes: From similarity based to category based attribution. *Human Development*, **32**, 79-87.

Inagaki, K. (1990a). The effects of raising animals on children's biological knowledge. *British Journal of Developmental Psychology*, **8**, 119-129.

Inagaki, K. (1990b). Young children's use of knowledge in everyday biology. *British Journal of Developmental Psychology*, **8**, 281-288.

Inagaki, K. (1993a). *Young children's differentiation of plants from nonliving things in terms of growth*. Paper presented at the biennial meeting of the Society for Research in Child Development, New Orleans.

Inagaki, K. (1993b). *The nature of young children's naive biology*. Paper presented at the symposium,"Children's naive theories of the world," at the 12th meeting of the International Society for the Study of Behavioral Development, Recife, Brazil.

Inagaki, K. & Hatano, G. (1987). Young children's spontaneous personification as analogy. *Child Development*, **58**, 1013-1020.

Inagaki, K. & Hatano, G. (1990). *Development of explanations for bodily functions*. Paper presented at the 32nd annual convention of the Japanese Association of Educational Psychology, Osaka. (in Japanese).

Inagaki, K. & Hatano, G. (1991). Constrained person analogy in young children's biological inference. *Cognitive Development*, **6**, 219-231.

Inagaki, K. & Hatano, G. (1993). Young children's understanding of the mind body distinction. *Child Development*, **64**, 1534-1549.

Inagaki, K. & Hatano, G. (1994). *Effects of biological contexts on chilren's induction of human properties*. Paper to be presented at the 36th annual convention of the Japanese Association of Educational Psychology, Kyoto. (in Japanese).

Inagaki, K. & Kasetani, M. (1994). *Effects of hints to use knowledge about humans on young children's understanding of biological phenomena*. Paper to be presented at the 13th meeting of the International Society for the Study of Behavioral Development, Amsterdam.

Inagaki, K. & Sugiyama, K. (1988). Attributing human characteristics: Developmental changes in over- and underattribution. *Cognitive Development*, **3**, 55-70.

Inagaki, K. & Suzuki, Y. (1991). *The understanding of the mind body distinction in children aged 3 to 5 years*. Paper presented at the 33rd annual convention of the Japanese Association of Educational Psychology, Nagano. (in Japanese).

Johnson, K. E., Mervis, C. B., & Boster, J. S. (1992). Developmental changes within the structure of

the mammal domain. *Developmental Psychology*, **28**, 74-83.

Keil, F.C. (1992). The origins of an autonomous biology. In M.R. Gunnar & M. Maratsos (Eds.), *Modularity and constraints in language and cognition : The Minnesota symposia on child psychology* (vol. 25, pp. 103-137). Hillsdale, NJ : Erlbaum.

Kondo, H. & Inagaki, K. (1991). *Effects of raising goldfish on the grasp of common characteristics of animals.* Paper presentd at the 44th meeting of the Japanese Association of Early Childhood Education and Care, Kobe. (in Japanese)

Kuhn, D. (1989). Children and adults as intuitive scientists. *Psychological Review*, **96**, 674-689.

Kyokuchi method in science education (1974). Unit on animals' bodily structures and their ways of living. Unpublished text. (in Japanese)

Massey, C.M. & Gelman, R. (1988). Preschooler's ability to decide whether a photographed unfamiliar object can move itself. *Developmental Psychology*, **24**, 307-317.

Morita, E., Inagaki, K. & Hatano, G. (1988). *The development of biological inferences : Analyses of RTs in children's attribution of human properties.* Paper presented at the 30th annual convention of the Japanese Association of Educational Psychology, Naruto. (in Japanese)

Motoyoshi, M. (1979). *Essays on education for day care children : Emphasizing daily life activities.* Tokyo : Froebel kan. (in Japanese)

Ohmori, S. (1985). *The structure of knowledge and science.* Tokyo : Nihon Hoso Shuppan Kyokai. (in Japanese)

Richards, D.D. & Siegler, R.S. (1984). The effects of task requirements on children's life judgments. *Child Development*, **55**, 1687-1696.

Richards, D.D. & Siegler, R.S. (1986). Children's understandings of the attributes of life. *Journal of Experimental Child Psychology*, **42**, 1-22.

Rosengren, K.S., Gelman, S.A., Kalish, C.W., & McCormick, M. (1991). As time goes by : Children's early understanding of growth. *Child Development*, **62**, 1302-1320.

Siegal, M. (1988). Children's knowledge of contagion and contamination as causes of illness. *Child Development*, **59**, 1353-1359.

Springer, K. & Keil, F.C. (1989). On the development of biologically specific beliefs : The case of inheritance. *Child Development*, **60**, 637-648.

Springer, K. & Keil, F.C. (1991). Early differentiation of causal mechanisms appropriate to biological and nonbiological kinds. *Child Development*, **62**, 767-781.

Stavy, R. & Wax, N. (1989). Children's conceptions of plants as living things. *Human Development*, **32**, 88-94.

Vera, A.H. & Keil, F.C. (1988). *The development of inductions about biological kinds : The nature of the conceptual base.* Paper presented at the 29th meeting of the Psychonomic Society, Chicago.

Vosniadou, S. (1989). Analogical reasoning as a mechanism in knowledge acquisition : A developmental perspective. In S. Vosniadou & A. Ortony (Eds.), *Similarity and analogical reasoning* (pp. 413-469). Cambridge : Cambridge University Press.

Wellman, H.M. (1990). *The child's theory of mind.* Cambridge, MA : MIT Press.

Wellman, H.M., & Gelman, S.A. (1992). Cognitive development : Foundational theories of core domains. *Annual Review of Psychology*, **43**, 337-375.

ACOUSTIC ANALYSIS OF NATURAL MATERNAL SPEECH TO PRESCHOOL LANGUAGE IMPAIRED AND NORMAL CHILDREN

Debora L. Scheffel
Fort Hays State University
Murray Alpert
New York University Medical Center Millhauser Laboratory

Acoustic characteristics of the speech of nineteen mothers to their normal and language impaired four year olds during a story reading task were analyzed on four scales of Expressiveness, Rate, Utterance Based Productivity, and Pause Based Productivity. Mother's audiotaped voices were digitized and then band pass filtered and analyzed by the computer system, VOXCOM. Discriminant function analysis correctly classified 84.2% of the mothers of language impaired children based on values representing the acoustic scales. The Expressiveness and Rate scales contributed the greatest discriminatory power to differentiating between the two groups of mothers. The results were interpreted in light of the importance of expressiveness and rate for focusing attention and consequent cognitive development.

Introduction:

Acoustic analysis of mother's speech to their children has traditionally been limited to speech with young children, those less than three years of age, and particularly, eighteen to twenty one months of age (Owens, 1988). The purpose of this research has been to document the presence of a specialized speech register used by primary care givers in speaking to young language learning children (Nelson, 1973; Wells, 1981; Snow, Dubber and De Blauw, 1982; Snow and Fergusen, 1977; Schachter and Strange, 1982; Cross, 1977). This register has been called "motherese" and has been interpreted as a consistent and simplified model from which the child can learn language, particularly syntax (Newport, Gleitman and Gleitman, 1977).

Early speech to young children has been generally found to consist of short, grammatically accurate sentences with many exclamations, use of high pitch and special voice qualities such as whispering, slower rate of speech, frequent repetitions, and baby talk words; and frequent use of questions and elaborations of the child's utterances (Garnica, 1977; Snow and Ferguson, 1977; Snow, 1984). Six acoustic features of mother's speech to young children isolated by Garnica (1977) include higher funda-

Address correspondence to: Debora L. Scheffel, Ph. D. 600 Park Street, Rarick 210, Fort Hays State University Hays, Kansas 67601, USA. The authors wish to thank Mr. John A. Ross, M. A., Computing and Telecommunications Center, Fort Hays State University, Hays, Ks., for his assistance in data analysis and in manuscript preparation.

mental frequency, greater pitch range, rising terminal frequency, longer duration in speaking separable verbs, and placing two primary syllabic stresses on words calling for one. Acoustic features have been found to be instrumental in focusing attention, differentiating given from new information, differentiating speech acts and syntactic structures, signalling organizational boundaries, and improving intelligibility and retention of meaning (Bates and MacWhinney, 1979; Clark and Clark, 1977; Crystal, 1981; Wode, 1980; Campbell and Shriberg, 1982; Wingfield, Lombardi, and Sokol, 1984).

In spite of the significance of and interest in acoustic analysis of mother's speech to their young children, studies to date have been conducted primarily with children younger than age three, have used imprecise instrumentation and subjective estimations of acoustic characteristics (Shute and Wheldall, 1989), and have not included comparisons across diagnostic categories as regards acoustic features.

The present investigation seeks to analyze acoustic aspects of mother's speech to their four year old children from the perspective of their significance for cognitive development. It is recognized that the child's knowledge structure is fully reorganized between the ages of four and ten years (Carey, 1987). This reorganization is based on prerequisite attention which is tightly connected to linguistic components in regulating activity (Zaporozhets and Elkonin, 1971; Wertsch, 1985). The formation of attention begins with the adult using words in characteristic ways to attract the child's attention to various aspects of reality. Gradually the child learns to organize his own attention based on his interaction with significant others. Acoustic characteristics reflect the reciprocal relationship or lack thereof, between the adult and child. The intonational envelope, as it has been called, signals joint participation between the adult and child (Bruner, 1975). This joint attention is the foundation on which later reorganization of knowledge structures is based (Dimitracopoulou, 1990).

In contrast to the often imprecise instrumentation used in other studies exploring acoustic aspects of mother's speech to young children, it is the purpose of this investigation to identify differences in speech to normal versus language impaired children using a unique computer based speech analysis system, VOXCOM. VOXCOM is a uniquely precise system using a microcomputer which provides a means to analyze recorded samples of natural speech in real time. The VOXCOM system was originally designed to provide objective and quantitative characterizations of the speech patterns found in various clinical populations. Its primary use thus far has been with schizophrenic and clinically depressed adult patients to identify the patients' ability to express emotion or affect. Initial studies indicate that acoustic cues may differentiate some of these clinical groups. This investigation seeks to extend the application of acoustic analysis using VOXCOM to differentiate between speech by mothers to normal versus language impaired children. Since language impaired children have been found to have deficits in social and linguistic interactional knowledge and competence (Bryan, 1981), acoustic features of maternal speech with normal and clinical populations may initially be a way to differentiate these groups and ultimately, help predict concomitant attentional and subsequent cognitive characteristics.

Method :

The subjects for this study are two groups of mother child dyads, ten normal child-mother pairs and nineteen language impaired children and their mothers. All children participating in the study are between the ages of 4 ; 0 and 5 ; 1, have demonstrated age deviation scores between 90 and 116 on an intelligence measure (Burgemeister, et al., 1972), and are boys. Dyads participating in the study are representative of the middle to upper middle socioeconomic level as determined by Hollingshead's Two Factor Index of Social Position (Meyers and Bean, 1968). Only families whose primary language is English were included in the present investigation, and all mothers and their children were Caucasian in ethnic origin. All subjects had normal auditory acuity and normal or corrected visual acuity. Normal children had demonstrated language competence on a locally devised screening measure which included assessment of expressive and receptive language abilities. No children in this group were known to have any language or emotional disorders and had not been referred for special education services of any kind. Language impaired subjects had been diagnosed by private or public agencies as evidencing a significant language disorder according to the State (of Colorado) guidelines, and were enrolled in an early intervention language program.

Mothers were engaged in a task in which each was given the same book (Crowe, 1980) to read to their preschool child. Reading has been found to be a preferred measure for analyzing acoustic characteristics of speech as it yields a high test-retest correlation and accurately reflects measurements of spontaneous speech (Fitch, 1990). Reading sessions were conducted in the mother's homes in a naturalistic setting and audiotaped. The analog signals from the mother's audiotaped reading of the story text were digitized and then band-pass filtered and analyzed by a computer system, VOXCOM (Alpert, et al., 1986). The range of the band passed filters is adjusted to accommodate specific samples of speech. For men the range extends from 80-140 Hz while women have a range extending 120 to 280 Hz. After filtering, the signal that represents the subjects voice is split into two parallel lines that are analyzed for frequency and amplitude information. In short, variations in voltages across time correlate with changes in loudness or stress that the subject produces. Consequently, usable data can be extrapolated from the raw data through the VOXCOM method. Figure 1 illustrates how the raw data would appear on an oscilloscope screen.

Data is reported in the form of *utterances*, *gaps*, and *peaks*. In addition, VOXCOM breaks those groups into subgroups representing the number of utterances, gaps, peaks ; the mean and variance of the time durations of utterances, gaps, and peaks ; the mean and variance of the log of the amplitudes of peaks and the frequencies corresponding to those peaks ; the correlation between peak amplitude and peak frequency ; and the distribution of peaks within utterances. The output of VOXCOM is shown in Table 1.

An *utterance* is defined as an amplitude which is above a given threshold of background noise for 100 msec. A *gap* is an amplitude that remains below the threshold for at least 200 msec. A *peak* is a point of maximum amplitude relative to the values of amplitude immediately preceding and following that point. As VOXCOM samples the raw data, it stores the values of amplitude and frequency and then compares each suc-

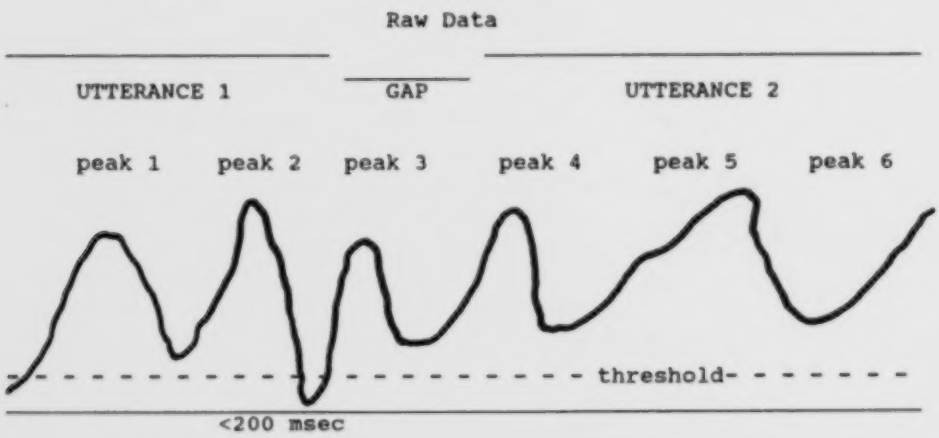


FIGURE 1 Hypothetical oscilloscopic tracings of two samples of speech to illustrate how VOXCOM detects a gap between utterance.

TABLE 1
VOXCOM Output

Parameters: id1 = 2 id2 = 32005 id3 = 2
gapmin = 20 utrmin = 10 pkminh = 51
thresh = 48 fmin = 200 fmax = 800
acalib = 0 fcalib = 0 fcalib2 = 0 uttkccp = 5

Total Time: 436 seconds

Utterances: N = 114
Mean Duration = 244.54 Variance = 32569.15
Frequency Distribution:
3 2 6 11 5 4 6 7 3 8 5 5 5 4 4 4 32

Gaps: N = 113
Mean Duration = 111.71 Variance = 20331.29
Frequency Distribution
0 29 19 11 9 4 9 8 3 3 0 2 1 0 2 1 4

All peak Data: N = 1141 r = 0.397

Duration		Amplitude		Frequency	
Mean	Var	Mean	Var	Mean	Var
23.8	119.77	536.5	131.33	491.9	95.88

Duration of n peak utterances:

#pk	N	mean	var
1 utt	7	28.3	189.1
3 utt	18	68.0	223.1
5 utt	13	126.3	848.1
7 utt	14	169.1	926.1
9 utt	10	202.8	949.1
11 utt	14	263.1	1020.1
13 utt	11	309.4	1021.1
15 utt	5	348.8	2024.1

ceeding value with the previous one. This identifies whether or not amplitude increases or decreases. Measures of uttmin and gapmin (minimum time duration for detecting whether an utterance or gap has occurred), pkminh (the minimum decrement in amplitude needed for a peak to be detected), thresh (the threshold or minimum amplitude that is considered usable signal by the peak detection routine), and fmin and fmax (minimum and maximum values of peak frequency accepted after band passing) are further used as criterion values against which analyze the data. With the use of frequency parameters, the VOXCOM system becomes a more precise method of controlling peak frequencies that are accepted as values of fundamental frequency.

From the computer-based VOXCOM speech analysis system, scales of Expressiveness, Utterance and Pause Based Productivity, and Rate have been developed. These scales represent average values derived from duration, variance, gap, rate, and peak information. Table 2 summarizes the components which comprise each of the scales.

TABLE 2

Variable Scale Components

Pause Based Productivity (PRD P)
Subject pause duration
Variance of subject pause duration
Gap at the 90th %ile
Gap at the 50th %ile
Rate of peaks per total time
Utterance Based Productivity (PRD U)
Subject vocalization duration
Variance of vocalization duration
Utterance duration at 90th %ile
Utterance duration at 50th %ile
Percent of 1 peak monosyllabic utterances/total utterances
Rate
Rate of peaks per time talking
Average duration of 3 peak utterances
Average duration of 4 peak utterances
Average duration of 5 peak utterances
Average duration of 6 peak utterances
Average duration of 7 peak utterances
Average duration of a peak
Variance of peak duration
Expressiveness
Frequency variance in 100ths of an octave
Amplitude variance
Variance of 1 peak amplitude
Variance of 2 peak amplitudes
Variance of 3 peak amplitudes
Variance of 4 peak amplitudes
Variance of 5 peak amplitudes
Variance of 1 peak frequency
Variance of 2 peak frequencies
Variance of 3 peak frequencies
Variance of 4 peak frequencies
Variance of 5 peak frequencies

The data generated from VOXCOM was analyzed using the SPSS/PC+ statistical software application. Table 3 shows the standardized means (i.e. converted to z scores) for both groups, the language impaired child-mother dyads and the normal child-mother dyads representing the dependent variables.

These means were compared across each of the four independent variables, Expressiveness, Rate, Pause and Utterance-Based Productivity. A one way analysis of variance (ANOVA) was used to compare the two groups in terms of their mean scores on each of the acoustic variables. Further manipulation of the data required the application of discriminant function analysis.

Results:

Results of the statistical anlaysis using a one-way analysis of variance (ANOVA) to compare the two groups across the four acoustic variables was not significant. Discriminant analysis of the four acoustic variables did not produce a significant deqree of separation between the two groups of mothers of language impaired versus mothers of normal children (Wilk's lambda = .81 $p < .05$). However, predictions as to category membership based on the four acoustic variables suggest trends which are noteworthy.

The discriminant procedure computes a linear composite of predictor variables that were used to classify children into either the normal or language impaired child-mother dyads. The results are presented in Table 4.

Inspection of Table 4 shows that the probability of correctly classifying a mother as speaking to a language impaired versus a normal child based on the four acoustic variables, is 84.2%. The probability of identifying a mother speaking to a normal child is 70%. The extent to which each acoustic measure contributes to the differentiation between the two groups is shown by the resulting discriminant

TABLE 3

Standardized Means

	Normal	L.D.
Expressiveness	.1897	−.0999
PRD-P	−.1018	.0536
PRD-U	.0681	−.0358
Rate	.2416	−.1271

TABLE 4

Classification Results

Actual Group	No. of Cases	Predicted Correct Gp. Membership	Incorrect
Normal	10	7	3
		70%	30%
L.D.	19	16	3
		84.2%	15.8%

coefficients for each variable, presented in Table 5.

As shown in Table 5, the variables most associated with group differernces are Rate and Expressiveness. Pause-Based Productivity and Utterance-Based Productivity contribute in that order of importance, to further differentiating the groups. Table 3 provides the mean scores on the four acoustic scales as a function of group membership for the normal child-mother dyads, and the language impaired child-mother dyads. As

TABLE 5

Discriminant Function Coefficients

PRD P	−.21076
PRD U	.13147
Rate	.65657
Expressiveness	.46111

TABLE 6

Z Scores

Subject Number	Group	PRD P	PRD U	EXP	RATE
1	0	− .13	− .86	− .70	− .01
2	0	− .88	− .76	1.06	.33
3	0	− .10	− .03	− .32	.01
4	0	−1.43	.42	.48	− .68
5	0	− .93	.54	− .64	.23
6	0	1.06	− .01	.10	.70
7	0	.06	− .27	.22	.32
8	0	.82	− .56	2.05	1.98
9	0	− .98	− .92	− .54	.29
10	0	1.48	3.11	.17	− .76
1	1	− .06	− .82	− .70	.59
2	1	.83	− .12	.12	− .49
3	1	.11	− .07	.42	− .59
4	1	.39	− .33	− .38	− .94
5	1	− .06	.55	1.25	− .55
6	1	− .04	.74	− .57	− .32
7	1	.29	− .54	− .14	− .02
8	1	.44	.67	− .18	− .48
9	1	.07	− .28	.04	.06
10	1	.96	.33	.16	− .22
11	1	− .19	.77	.83	− .25
12	1	− .30	.33	− .73	− .59
13	1	− .15	.26	.15	− .24
14	1	− .23	− .53	− .59	.40
15	1	.31	− .64	− .58	.11
16		not available			
17	1	−1.67	− .63	.00	.66
18	1	.14	.59	− .51	− .55
19	1	−1.00	.07	− .55	.60
20	1	1.19	−1.04	.04	.41

TABLE 7

Discriminant Scores (**) Misclassified

Subject Number	Classified Group	Highest Group	Probability	Discriminate Score
1**	0	1	.4625	−1.0640
2	0	0	.8788	.7780
3**	0	1	.8124	− .0920
4	0	0	.6740	.2049
5	0	0	.5898	1.1646
6	0	0	.9587	.6773
7	0	0	.7998	.3720
8	0	0	.0065	3.3445
9**	0	1	.7930	− .0668
10	0	0	.7555	.9370
1	1	1	.7538	− .0156
2	1	1	.2961	−1.3740
3	1	1	.5117	− .9854
4	1	1	.0443	−2.3404
5	1	1	.6422	.1354
6	1	1	.7834	− .0543
7	1	1	.6521	− .7801
8	1	1	.8497	− .5187
9	1	1	.8878	− .1882
10	1	1	.8335	− .5394
11**	1	0	.8900	.7639
12	1	1	.6030	− .8493
13	1	1	.7584	− .0216
14	1	1	.6898	.0699
15	1	1	.6045	− .8472
16		not available		
17**	1	0	.3976	1.4715
18	1	1	.7117	− .6988
19**	1	0	.4161	1.4387
20	1	1	.5536	− .9217

shown in Table 3, mothers reading to their language impaired children evidenced a slower rate of reading than mothers of normal children, lower utterance based productivity, higher pause based productivity, and depressed expressiveness.

The discriminant scores were used to classify the subjects according to group membership across the four acoustic scales.

Discussion:

Acoustic characteristics of mother's speech to normal or handicapped children have not been extensively studied. When they have been the subject of inquiry, they have often been described subjectively and with respect to chiidren younger than age three learning language. The significance of the present investigation is in applying precise instrumentation to analysis of acoustic characteristics of mother's speech to children across normal and language impaired categories after they have passed the traditional "motherese" language learning years. The results are significant in that

they document that characteristic acoustic features of mother's speech to children persist beyond the initial language learning years and that these features may be absent or less pronounced in mother's speech to language impaired children, thus helping to discriminate normal from clinically diagnosed children.

The concept of intersubjectivity as discussed by Bruner (1977), Schaffer (1977) and Trevarthen (1979) is instructive in interpreting the results of the present study. These authors suggest that mothers and their children seek to achieve a degree of shared emotional and intellectual understanding within their interactions. Intersubjectivity may be disrupted or changed by interactions in which the mother's responsiveness to the child is compromised. Solmit and Stark (1961), Emde and Brown (1978) and others have documented the presence of negative emotional maternal responsiveness to their handicapped children due to a violation of maternal expectations within the interaction. Depending on etiologic differences and severity of the disorder, a mourning process often occurs resulting in less frequent and positive mother-child interactions.

Another factor which may affect the intersubjectivity or shared intellectual and emotional understanding between mothers and their language impaired children is that mothers of handicapped children have been observed to be generally directive in their interactions. For example, Jones (1980) found that mothers of Down Syndrome children often referred to interactive sessions as teaching sessions and considered a good interaction to be one in which the children had been successfully instructed. In contrast, mothers of non-handicapped children considered a good interaction to be one in which a playful experience had been shared. MacDonald and Gillette (1988) conclude that there are considerable differences between the manner that mothers interact with language handicapped and normally developing children and that these differences are not well suited for either engaging these children in interaction or promoting their development. Specifically, adults seem to expect a delayed child not to stay engaged in a given conversation. Parents often communicate rhetorically, that is, at the child rather than for a response, suggesting that some adults may view the function of their talk as being to deposit language in the child rather than to teach the child how to use language. Decreased responsiveness and increased maternal dominance and directiveness are often the result, which may have specific cognitive outcomes for the child.

Abundant correlational research exists to suggest that maternal behavior influences young children's cognitive development (e.g. Feshbach, 1973; Schachter, 1979; White and Watts, 1973). Research linking the nature of mother-child interactions to later outcomes suggests that handicapped children are less likely to tackle difficult problems, show lower self images, and adopt a problem solving style characterized by looking to others for solutions (Zigler, 1971; Hodapp, 1988). Mahoney (1988) suggests that the interactional characteristics, including decreased parental responsiveness, he observed in mother-handicapped child dyads, appear to be related to phenomenon that affect the child's motivation to achieve competence. These phonomenon include locus of control, feelings of competence, and interest level.

Four years of age, the age of the children in the present study, is considered a crucial point in the development of the child in that expanded language and abstract reasoning skills tend to emerge at this time (Bruner, 1973). In his study with four

year olds and their mothers, Slater (1986) found that children whose mothers employed a concrete, directive, nonresponsive form of interaction, evidenced depressed scores on a standardized aptitude measure, as compared with children of mothers who employed a more responsive interaction style. Similarly, Pianta and Erickson (1990) found that mother child interaction variables, including negative affect on the part of the mother, predicted referral for special services at 42 months and that referred children performed significantly more poorly on a standardized aptitude measure than non referred children.

In the present study, mothers of the language impaired children showed a trend toward a slower rate of speech, lower verbal productivity, more pause time, and depressed expressiveness with their children than mothers of normal children. Based on related research, it appears that some of these characteristics may have important negative implications for developing a shared intellectual and emotional context between mothers and their language impaired children within which cognitive development is nurtured and shaped. Current understanding of prosodic features of mother's speech to children, specifically, exaggerated expressiveness relates to holding the attention of the child. Given the lack of expressiveness in mothers speaking to their language impaired children identified in the current study, implications are clear for altered attention which is the foundation for cognitive development. It appears that while mothers are slowing down the rate of their verbal presentation for their language impaired children, they may be compromising expression and hence attention and cognitive development, as well.

Given the present descriptive study, future investigations with larger subject pools and digital data collection methodology may help reduce some of the variability characterizing the present data set. Further, future studies may focus on correlating acoustic features with attentional or cognitive variables in members of communicative dyads under scrutiny. Finally, the results of the present investigation add to information used to discriminate diagnostic categories and predict subsequent cognitive characteristics.

REFERENCES

Alpert, M., Merewether, F., Homel, P., Martz, J., and Lomask, M. (1986). Voxcom: A system for analyzing natural speech in real time. *Behavior, Research Methods, Instruments and Computers*, **18** (2), 267-272.

Bates, E., and MacWhinney, B. (1979). A functionalist approach to the acquisition of grammar. In E. Ochs and B. Scheffelin (Eds.), *Developmental Pragmatics* (pp. 167-211). New York: Academic Press.

Bruner, J. (1973). *On knowing: Essay for the left hand.* New York: Antheneum.

Bruner, J. (1975). From communication to language: A psychological perspective. *Cognition*, **3**, 255-287.

Bruner, J. (1977). Early social interaction and language acquisition. In H. R. Schaffer (Ed.), *Studies in mother-infant interactions.* New York: Academic Press.

Bryan, J. H. (1981). Social behaviors of learning disabled children. In J. Gottlieb & S. Strichart (Eds.), *Developmental theory and research in learning disabilities.* Baltimore, Md.: University Park Press.

Bargmeister, B., Blum, J., & Lorge, I. (1972). *Columbia mental maturity scale*. New York: Harcourt, Brace, Jovanovich.

Campbell, T. & Shriberg, L. D. (1982). Associations among pragmatic functions, linguistic stress, and natural phonological process in speech delayed children. *Journal of Speech and Hearing Research*, **25**, 547–553.

Carey, S. (1985). *Conceptual Change in Childhood*. Cambridge, Massachusetts: M.I.T. Press.

Clark, H. H. and Clark, E. V. (1977). *Psychology and language: An introduction to psycholinguistics*. New York: Harcourt, Brace, Jovanovich.

Cross, T. G. (1977). Mothers speech adjustments: The contribution of selected child listener variables. In C. E. Snow and C. A. Ferguson (Eds.), *Talking to children: Language input and acquisition*. New York: Cambridge University Press.

Crowe, R. (1980). *Tyler toad and the thunder*. New York: Dutton.

Crystal, D. (1981). *Clinical linguistics*. New York: Springer Verlag.

Dimitracopoulou, I. (1980). *Conversational competence and social development*. Cambridge: Cambridge University Press.

Emde, R., and Brown, C. (1978). Adaptation to the birth of a Down's Syndrome infant: Grieving and maternal attachment. *Journal of the American Academy of Child Psychiatry*, **17**, 299–323.

Feshbach, N. (1973). Cross cultural studies of teaching styles in four year olds and their mothers. In A. D. Pick (Ed.), *Minnesota symposia on child psychology* (Vol 7, pp. 86–116). Minneapolis: University of Minnesota Press.

Fitch, J. (1980). Consistency of fundamental frequency and perturbation in repeated phonations of sustained vowels, reading, and connected speech. *Journal of Speech and Hearing Disorders*, **55**, 360–363.

Garnica, O. K. (1977). Some prosodic and paralinguistic features of speech to young children. In C. Snow and C. Ferguson (Eds.), *Talking to children: Language input and acquisition* (pp. 63–88). Cambridge: Cambridge University Press.

Hodapp, R. (1988). The role of maternal emotions and perceptions in interactions with young handicapped children. In K. Marfo (Ed.), *Parent Child interaction and developmental disabilities* (pp. 32–46). New York: Praeger.

Jones, O. (1980). Prelinguistic communication skills in Down's Syndrome and normal infants. In T. M. Field, S. Goldberg, D. Stern, and A. Sostek (Eds.), *High risk infants and children: Adult and peer interactions*. New York: Academic Press.

MacDonald, J., and Gillette, Y. (1988). Communicating partners: A conversational model for building parent child relationships with handicapped children. In K. Marfo (Ed.), *Parent Child interaction and developmental disabilities* (pp. 220–241). New York: Praeger.

Mahoney, G. (1988). Enhancing the developmental competence of handicapped infants. In K. Marfo (Ed.), *Parent child interactions and developmental disabilities* (pp. 203–219). New York: Praeger.

Myers, J., and Bean, L. (1968). *A decade later: A followup of social class and mental illness*. New York: Wiley.

Nelson, K. (1973). Structure and strategy in learning to talk. Monographs of the society for research in child development, **38** (1–2, Serial No. 149).

Newport, E., Gleitman, A., & Gleitman, L. (1977). Mother, I'd rather do it myself: Some effects and noneffects of maternal speech style. In C. Snow & C. Ferguson (Eds.), *Talking to children: Language input and acquisition*. New York: Cambridge University Press.

Owens, R. (1988). *Language development: An introduction*. Columbus, Ohio: Merrill Publishing.

Pianta, R., Erickson, M., Wagner, N., Kreutzer, T., and Egeland, B. (1990). Early Predictors of referral and special services: Child based measures versus motherchild interaction. *School*

Psychology Review, **19** (2), 240–258.

Schachter, F. F. (1979). *Everyday mother talk to toddlers: Early intervention*. New York: Academic Press.

Schachter, F. F., and Strage, A. (1982). Adults' talk and children's language development. In S. Moore & C. Cooper (Eds.), *The young child: Reviews of research* (Vol. 3). Washington, D. C.: National Association for the Education of Children.

Schaffer, H. (Ed.). (1977). *Studies in mother–infant interaction*. New York: Academic Press.

Shute, B., & Wheldall, K. (1988). Pitch alterations in British motherese: Some preliminary acoustic data. *Journal of Child Language*, **16**, 503–512.

Slater, M. (1986). Modification of mother–child interaction processes in families with children at risk for mental retardation. *American Journal of Mental Deficiency*, **91** (3), 257–267.

Snow, C. E., and Ferguson, C. A. (1977). *Talking to children: Language input and acquisition*. Cambridge: Cambridge University Press.

Snow, C. E., Dubber, C., & De Blauw, A. (1982). Routines in mother–child interaction. In L. Feagans & D. C. Farran (Eds.), *The language of children reared in poverty: Implications for evaluation and intervention*. New York: Academic Press.

Snow, C. E. (1984). Parent–child interaction and the development of communicative ability. In R. L. Schiefelbusch and J. Pickar (Eds.), *The acquisition of communicative competence* (pp. 69–108). Baltimore: Md.: University Park Press.

Solnit, A., and Stark, M. (1961). Mourning and the birth of a defective child. *The Psychoanalytic Study of the Child*, **16**, 523–537.

Trevarthen, C. (1979). Communication and cooperation in early infancy. In M. Bullowa (Ed.), *Before speech*. Cambridge: Cambridge University Press.

Wells, G. (1981). *Learning through interaction. The study of language development*. New York: Cambridge University Press.

Wertch, J. (1985). *Vygotsky and the social formation of mind*. Cambridge: Harvard University Press.

White, B., and Watts, J. (1973). *Experience and environment* (Vol. 1). Englewood Cliffs, New Jersey: Prentice Hall.

Wingfield, A., Lombardi, L., and Sokol, S. (1984). Prosodic features and the intelligibility of accelerated speech: syntactic versus periodic segmentation. *Journal of Speech and Hearing Research*, **27**, 128–134.

Zaporozhets, A. and Elkonin, D. (1971). *The psychology of preschool children*. Cambridge, Massachusetts: M.I.T. Press.

Zigler, E. (1971). The retarded child as a whole person. In H. E. Adams and W. K. Boardman (Eds.), *Advances in Experimental Clinical Psychology*. New York: Pergamon Press.

COMPREHENSION, IMITATION, AND PRODUCTION OF SIMPLE SENTENCES IN MENTALLY RETARDED INDIVIDUALS.

Toshiharu Matsumoto
Muroran Institute of Technology
Takashi Furutsuka
Hokkaido University

The purpose of this study is to investigate the relationships between sentence comprehension, sentence imitation, and sentence production in mentally retarded individuals. Thirty two mentally retarded individuals, aged from 16 to 37 years old, with 29 males and 3 females, were tested. In the first experiment, subjects acted out simple sentences using miniature toys. In the second experiment, subjects were asked to imitate simple sentences. In the third experiment, subjects were asked to draw an event on a picture about the following; "one animal chased another". The results of these experiments indicated: 1) even the subjects who showed event probability strategy in sentence comprehension tasks could use the word order in the sentence production tasks; 2) the subjects of the event probability strategy apply wrong particles in sentence imitation tasks and sentence production tasks.

Introduction

Numerous attempts have been made by researchers to show problems of langauge learning in mentally retarded individuals. However, comprehension and production were researched separatively. A few attempts have been made in terms of the relationships between comprehension and production. The purpose of this study is to investigate sentence formats and assignment of actor patient relationships in sentence production task for each sentence comprehension strategy.

Mentally retarded individuals and normal children are known to comprehend a simple sentence with different ways from that of adults'. Bever (1970) investigated sentence comprehension of children, finding a semantic strategy at 3 years old, and a word order strategy at 4 years old. The semantic strategy is to comprehend a sentence according to the semantic constraints. The children who use the strategy could correctly comprehend the probable sentences like "The mother pats the dog," but not the improbable sentences like "The dog pats the mother." The word order strategy is to comprehend a sentence according to the word order. The children of the word order strategy regard the first noun as an actor and the second noun as an object.

In sentence comprehension of Japanese children, the semantic strategy, the word order strategy, and the particle strategy were found (Hayashibe, 1975; Suzuki, 1977; Iwatate, 1980). Japanese language is an subject-object-verb (S-O-V) language with a relatively free word order. The case relation is expressed by postpositional particles,

and the subject is marked by the particle "ga", the object by the particle "wo". A form of Japanese simple sentence is 'noun particle noun particle verb'. Since the positions of "noun particle" are exchangeable, the following two sentences are acceptable, that is, "subject ga object wo verb (SOV)" and "object wo subject ga verb (OSV)." Japanese children comprehend a sentence on the basis of the particles after 6 years old.

The sentence comprehension strategies of mentally retarded individuals were investigated by a few studies (Dewart, 1977; Bridges and Smith, 1984; Matsumoto, 1986, 1989). It is reported that mentally retarded individuals change the word order strategy for the semantic strategy between Mental Age (MA) 3 years old and 4 (Dewart, 1977; Bridges and Smith, 1984).

Matsumoto (1986, 1989) investigated the sentence comprehension of Japanese mentally retarded individuals that were asked to act out a simple sentence by using miniatures animals toys. He found the event probability strategy (the semantic strategy), the word order strategy, and the particle strategy in the mentally retarded individuals to be the same as in normal children. Furthermore, Matsumoto and Furutsuka (in press) examined the relationships between the sentence comprehension and the sentence imitation. They found that a) the subject who comprehended the particles could correctly imitate both SOV and OSV; b) some of the subjects who correctly imitated both SOV and OSV could not comprehend the particles; c) all subjects who participated in the experiment could correctly imitate the noun and the word order of the noun; d) some subjects change SOV for OSV in the imitation task. From the results they proposed a sentence comprehension model including two stages. In their model, at the first stage, the subject stores the simple sentence according to sentence formats in his linguistic repertoire. At the second stage, he/she decides the actor-patient relationship on the basis of a linguistic cue. The subjects having SOV and OSV formats can correctly store the sentences, and some of them use the particles for sentence comprehension. However some of them can not. Since the subjects having the SOV format alone miss the particles in the OSV sentences, they can not understand the OSV sentences. Some of them use the cue of the word order in sentence comprehension, and others comprehend the sentences on the basis of semantic constraints. The subjects who acquire neither the SOV format nor the OSV format can not use the cue of the particles in the comprehension tasks. Most of them comprehend the sentences according to semantic constraints.

In a similar way, the process of sentence production can be regarded as containing two stages, the sellection of a specific sentence format, and the assignment of an actor-patient relationship to the sentence format. In this sentence production experiment, the task is to describe the event that one animal chases another animal. The subject must understand the actor-patient relationships of the event, presenting it in a sentence some way. How do mentally retarded individuals represent the actor-patient relationship? What format do they use in sentence production tasks?

As mentioned in the above, the purpose here is to explore the relationships between sentence comprehension, sentence imitation, and sentence production in mentally retarded individuals. In the sentence comprehension experiment, the sentence comprehension strategy is identified. In the sentence imitation experiment, the

responses are analyzed in terms of the sentence format. In the sentence production experiment the sentence format and assignments of actor-patient relationships to word order are investigated.

Experiment I

Method

Subjects. The subjects were 32 mentally retarded individuals (29 males and 3 females), from a mental retardation institution in Sapporo City. Their chronological ages (CAs) ranged from 16 : 5 to 37 : 2 years (mean =26 : 11), their MAs assessed by Suzuki Binet Intelligence test ranged from 3 : 2 to 11 : 11 (mean=6 : 4), and their Intelligence Quotient (IQ) ranged from 20 to 74 (mean=41).

Materials. There were two variables in sentences: 1) sentence type (Subject-Object-Verb (SOV), or OSV); 2) semantic constraints (neutral, probable, or improbable). The combination of the two variables yielded six conditions. For each condition, four sentences were made.

The sentences used in this test were:

Probable and SOV sentences
- raion (lion) ga buta (pig) wo tsukamaeru (chases) (The lion chases the pig).
- raion ga hituji wo tsukamaeru (The lion chases the sheep).
- tora ga buta wo tsukamaeru (The tiger chases the pig).
- tora ga hitsuji wo tsukamaeru (The tiger chases the sheep).

Probable and OSV sentences
- buta wo raion ga tsukamaeru (The lion chases the pig)
- hitsuji wo raion ga tsukamaeru (The lion chases the sheep).
- buta wo tora ga tsukamaeru (The tiger chases the pig).
- hitsuji wo tora ga tsukamaeru (The tiger chases the pig).

Improbable and SOV sentences
- buta ga raion wo tsukamaeru (The pig chases the lion)
- hitsuji ga raion wo tsukamaeru (The sheep chases the lion).
- buta ga tora wo tsukamaeru (The pig chases the tiger).
- hitsuji ga tora wo tsukamaeru (The pig chases the tiger).

Improbable and OSV sentences
- raion wo buta ga tsukamaeru (The pig chases the lion)
- raion wo hitsuji ga tsukamaeru (The sheep chases the lion).
- tora wo buta ga tsukamaeru (The pig chases the tiger).
- tora wo hitsuji ga tsukamaeru (The pig chases the tiger).

Neutral and SOV sentences
- raion ga tora wo tsukamaeru (The tiger chases the lion).
- tora ga raion wo tsukamaeru (The lion chases the tiger).
- buta ga hitsuji wo tsukamaeru (The pig chases the sheep).
- hitsuji ga buta wo tsukamaeru (The sheep chases the pig).

Neutral and SOV sentences

tora wo raion ga tsukamaeru (The tiger chases the lion).
raion wo tora ga tsukamaeru (The lion chases the tiger).
hitsuji wo buta ga tsukamaeru (The pig chases the sheep).
buta wo hitsuji ga tsukamaeru (The sheep chases the pig).

The order of the presentations of sentences was pre randomized.

The miniature toys corresponding to the nouns in the sentence were provided.

Procedure. To identify the sentence comprehension strategy were applied the tests used by Matsumoto (1986). The subjects were individually tested in a quiet room in the institution. At the beginning the subject were asked to name the miniatures or to point to the one called by the experimenter. Most of the subjects could correctly name or point to the toys. If a subject could neither name nor point, a few practices were given to the subject. Instruction in trails is as follows: "The tape recorder speaks a sentence. Listen carefully and act out the sentence by using these miniatures." If the subject couldn't understand the requirement of the task, some practice was given. At first in a trial, the experimenter sets up vertically an untransparent board and a transparent board in front of the subjects and place four miniature animals toys behind the boards. Then the experimenter removes the untransparent board and switches on the tape recorder to say a sentence. The transparent board on the table prevents the subject from operating miniature toys during the presentation of a sentence. After the presentation of a sentence, the experimenter takes away the transparent board and urged the subject to act out the sentence. The subject's responses were recorded with a video tape recorder.

Results

The effects of the event probability, the word order, and the particle on the response were analyzed to identify the sentence comprehension strategy for each subject. The effect of the event probability was valued by the number of responses in which a strong animal (lion or tiger) chases a weak animal (sheep or pig). If the number of the response was beyond 12 in the 16 trials in which probable and improbable sentences were presented, the subject was identified to use the event probability strategy. The effect of the word order was valued by the number of the responses indicating that an animal of expressed by the first noun chases an animal expressed by the second noun. If the number of the responses was beyond 18, the subject was recognized as using the word order strategy. The effect of the particles was valued by the number of the correct responses. If a subject could correctly act out the sentence according to the particles on more than 18 trials, the subject was recognized as using the particle strategy. In the responses, an animal of the noun marked by "ga" chases an animal of the noun marked by "wo".

The number of the subjects for each comprehension strategy is shown in Table 1. Eight subjects use the event probability strategy, 8 subjects the word order strategy, and 6 subjects the particle strategy. Ten subjects were not classified into any strategies.

Experiment II

Method

Subjects. The subjects were the same as Experiment I.

Materials. The sentences were the same as Experiment I.

Procedure. The subjects were individually tested at the same room in Experiment I.

The subjects were asked to imitate the sentence that the experimenter had called. In the training session, three sentences were presented: "boku/watasi no uthi (My house)", "uma ha ookii (The horse is big)", "Bokura/watasitachi ha yoru neru (We sleep at night)". The sentences in this experiment were presented with pre-randomized order through a tape recorder.

Results

Presented in Figure 1 are the percentages of correct responses for event probability strategy group, the word order strategy group, and the particle strategy group. The correct response is that a subject correctly imitates all words including the particles. The analysis of variance (ANOVA) with respect to the number of correct response indicates that the difference between the groups is significant ($F(2, 21)=8.55$, $p<.01$). Thus Multiple Range Test of Scheffe was done, indicating that the number of

TABLE 1

Predominant sentence format for each subject in the imitation and production tasks.

subject	strategy	formats	
		imitation tasks	in production tasks
1	probability	OTHERS	OTHERS
2	probability	UNCLASSIFIED	OTHERS
3	probability	OTHERS	OTHERS
4	probability	OTHERS	OTHERS
5	probability	OTHERS	SOV
6	probability	SOV	SOV
7	probability	SOV	SOV
8	probability	SOV	SOV
9	word order	SOV + OSV	U
10	word order	OTHERS	OTHERS
11	word order	SOV	SOV
12	word order	OTHERS	U
13	word order	OTHERS	OTHERS
14	word order	SOV	SOV
15	word order	SOV + OSV	OTHERS
16	word order	SOV + OSV	SOV
17	particle	SOV + OSV	OSV
18	particle	SOV + OSV	SOV
19	particle	SOV + OSV	SOV
20	particle	SOV + OSV	SOV
21	particle	SOV + OSV	OSV
22	particle	SOV + OSV	SOV

correct responses in the particle strategy group is significantly superior to both that in the event probability group and that in the word order group ($p<.05$).

The sentences in the responses were classified into three types: SOV, OSV, and OTHERS. The percentages of SOV, OSV, and OTHERS are shown in Figure 2. The differences between the sentence comprehension strategy groups were analyzed with ANOVA for each type of sentence. The analyses indicate that the difference of OSV between the sentence comprehension strategy groups is significant ($F(2,21)=6.76$, $p<.01$). Then Multiple Range Test of Scheffe was done, displaying that the number of OSV in the particle strategy group is significantly superior to that in the other groups ($p<.01$). No significant difference between the sentence comprehension strategy groups was found with respect to SOV and OTHERS. Although the differences between the particles strategy group and other groups are very large about SOV, the difference is not significant.

In addition to these analyses, the predominant sentence formats were identified for each subject. If the number of a specified type of sentence was beyond 2/3 of the responses in a subject, it was judged to be the predominant format of the subject. If the number of a specified type of sentence was under 2/3 of the responses in a subject, the subject was judged to have more than two formats. In the subjects, the format that appears beyond 8 trials seemed to be his/her predominant formats. The predominant formats for each subject were shown in Table 1.

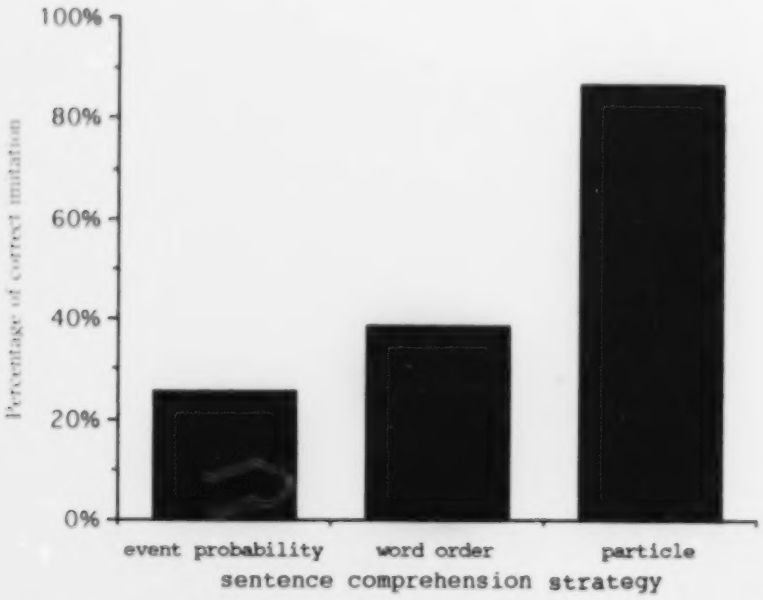


FIGURE 1 The percentage of correct imitation for each sentence comprehension strategy.

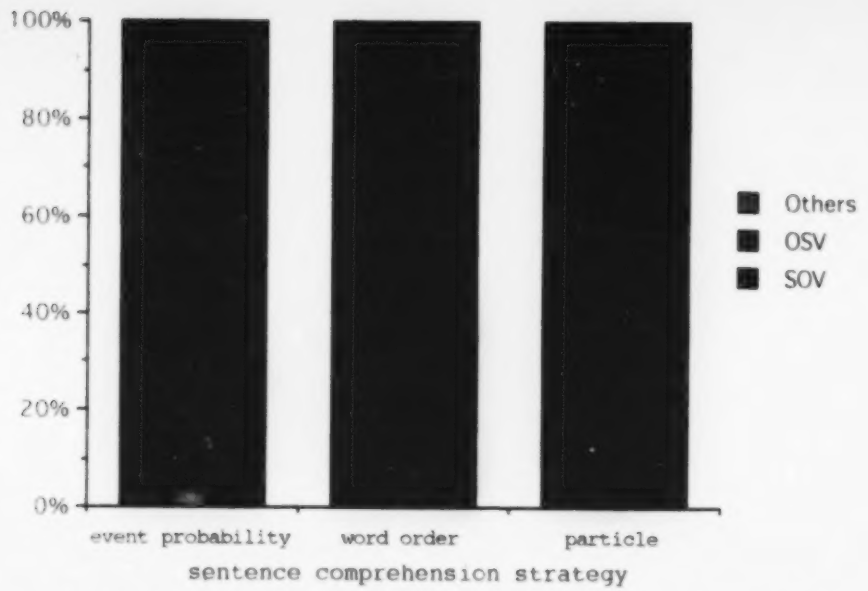


FIGURE 2 The percentage of SOV, OSV, and others in response of sentence imitation tasks.

Experiment III

Method

Subjects. The subjects were the same as Experiment I and II.

Materials. Twenty four cards, on which there was a picture that showed one animal chaseing an other animal, were presented to the subjects. These animals were a lion, a tiger, a pig, and a sheep. There were six ways in pairing the animals: a lion and a tiger, a lion and a pig, a lion and a sheep, a tiger and a pig, a tiger and a sheep, a pig and a sheep. For each pair four cards were made. On the first card is a picture showing that an animal (A) on the right hand side chases another animal (B) on the left hand side, second, B on the right hand side chases A on the left hand side, third, A on left hand side chases B on right hand side, fourth, that B on left hand side chases A on right hand side.

Procedure. The room for the test is the same as in Experiment I. The experimenter sits in front of the subject. After the naming task of the animals, subjects were instructed as follows: "I will show you a picture in which an animal chases another animal. Would you describe the picture." While the subject was responding, the card was presented. The 24 cards were given in pre random order.

Results

In the response, misnamings were found at six percent of the trials. No subject misnamed the animals in more than a half of the trials. Since misnamings seem to be triggered by carelessness, we eliminated the errors from our analysis.

We scored the figure of responses telling that the actor patient relationship was

correctly described by using the particles, "ga" and "wo". Fig.3 showed the percentage of the correct response for each strategy group. The differences between the sentence comprehension strategy groups were analyzed with ANOVA. The analysis indicates that the difference between sentence comprehension strategy groups is significant ($F(2,21)=8.32$ $p<.01$). Thus Multiple Range Test of Scheffe was done, displaying that the number of correct production in the particle strategy group is significantly superior to that in the other groups ($p<.05$).

The assignment of the actor patient relationship to word order was scored for each of the subjects. The assignment of the actor patient relationship to word order was that the actor was assigned to the first noun and the patient was second noun. For example, when the subject had seen a picture where a sheep chases a pig, he/she describes the sentence as "hitsuji (a sheep) particle buta (a pig) particle tsukamaeru (chase)." If the number of the assignments for a subject was significantly superior to a chance level, the subject was identified as using the assignments predominantly. The percentage of the subjects using the assignment for each sentence comprehension strategy can be seen in Fig.4: 75% for event probability strategy; 63% for word order strategy; 83% for particle strategy. There is no significant difference among the sentence comprehension strategy groups.

The sentences of the responses were classified in term of the sentence formats (Fig.5). The differences between the sentence comprehension strategy groups were analyzed with ANOVA for each type of sentence. No significant difference was found because the variations among the subjects were too large. The differences between SOV, OSV, and OTHERS were analyzed in the same way for each sentence comprehension strategy group. For the particle sentence comprehension strategy group, the

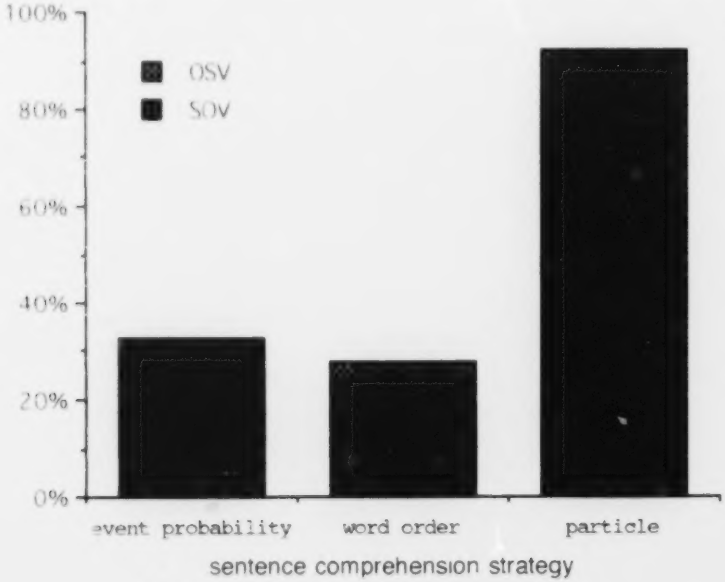


FIGURE 3 The percentage of correct production.

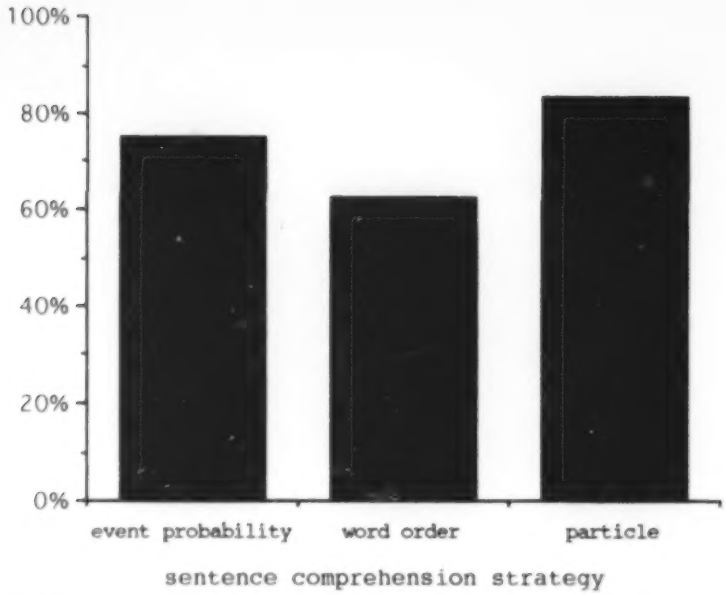


FIGURE 4 Percentages of the subjects who assign the actor patient relationships to word order.

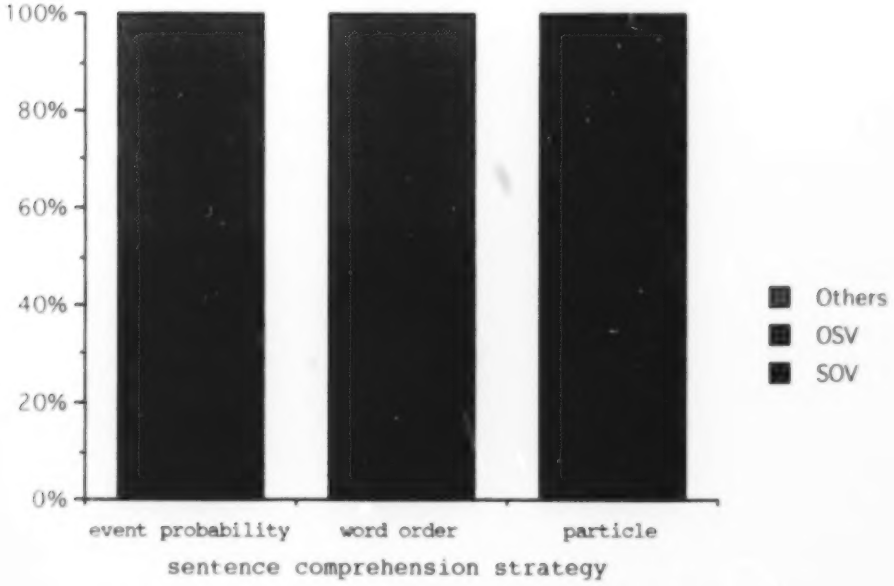


FIGURE 5 Percentage of SOV, OSV, and others in sentence production tasks.

main effect of sentence formats was found ($F(2,17)=10.17$, $p<.01$). The Multiple Range Test of Scheffe displayed that the number of SOV was significantly superior to both that of OSV and that of OTHERS ($p<.05$).

The sentence formats that are predominantly used in the responses are identified in the same way as in Experiment II. The predominant formats for each subject are presented in Table 1. Half of the event probability strategy group and the word order strategy group use neither SOV nor OSV formats in sentence production tasks, misusing the particles. The particle strategy group, on the other hand, correctly use the SOV or OSV formats.

Discussion

The result of the sentence imitation experiment is similar to that of Matsumoto and Furutsuka (in press). The subjects of the particle strategy group could correctly imitate both SOV and OSV. Many subjects of the event probability strategy group and the word order strategy group could not imitate the OSV. There is no difference between the event probability strategy group and the word order strategy group with respect to the sentence format.

The results of the sentence production tasks indicated that the subjects of the particle strategy group describe the event according to the sentences which include particle "ga" and "wo". The majority of the correct productions were SOV, and only a subject of the particle strategy group represents the event by using OSV. It is possible to built the two explanations for the reason that many subjects used the SOV format. First, the instruction, in which the experimenter presents the SOV formats as the model, leads to the usage of SOV. Second, the SOV is a canonical sentence in Japanese, and the subject is more familiar to the SOV formats than OSV formats.

A few researchers (Hakuta, 1972; Chapman and Miller, 1975; Goto, 1989) studied the relationships between sentence comprehension and sentence production. Chapman and Miller (1975) suggested that the production precede the comprehension. Goto (1989) found that the usage of the particle in production task precedes the comprehension of particles in Japanese normal children. In the present study some subjects of the word order strategy, who could not understand the particles in the sentence comprehension tasks, described the event on the picture by using the SOV format, which includes the particles. Taking into account the development of the sentence comprehension strategy (Hayashibe, 1975), it was obvious that the comprehension of the particles follows the utilization of particles in production in mentally retarded individuals.

We found the interesting fact in the assignment of the actor-patient relationship to the word order. The majority of the event probability groups, who cannot use the cue of word order in the sentence comprehension tasks, could assign the actor-patient relationship to word order in the sentence production tasks. In short, as for word order the production precedes the comprehension. No differences were found in the assignment between sentence comprehension strategy groups.

On the other hand, there are enormous differences of the sentence formats between the sentence comprehension strategy groups. In the event probability strategy group and the word order strategy group, nearly a half of the responses are other formats, which include the linguistically incorrect sentences. The differences of correct responses among sentence comprehension strategy in the sentence production tasks resulted from the differences of the sentence formats, which each sentence comprehen-

sion strategy group acquires.

REFERENCES

Bever, T.G. (1970). The cognitive basis for linguistic structures. In Ed. Hayes, J.R. (Eds.), *Cognitive and Development of Language*. New York: John Willey & Sons, 297-352.

Bridges, A. and Smith, J.V.E. (1984). Syntactic comprehension in Down's Syndrome children. *British Journal of Psychology*, **75**, 187-196.

Chapman, R.S. and Miller, J.F. (1975). Word order in early two and three word utterances: Does production precede comprehension? *Journal of Speech & Hearing*., **18**, 346-354.

Dewart, M.H. (1979). Language comprehension processes of mentally retarded children. *American Journal of Mental Deficiency*, **84**, 177-183.

Goto, K. (1989). Production and judgment of the case particles 'ga' and 'wo' in simple transitive sentences among preschool children. *Japanese Journal of Communication Disorders*, **6**, 12-19.

Hayashibe, H. (1975). Word order and particles: a developmental study in Japanese. *Description and Applied Linguistics*, **8**, 1-18.

Iwatate, S. (1980). The word order and case strategies in Japanese children. *Japanese Journal of Psychology*, **51**, 233-240.

Matsumoto, T. (1986). A study of the strategies for sentence comprehension in mentally retarded children. *Bulletin of The Faculty of Education Hokkaido University*, **48**, 207-227.

Matsumoto, T. (1989). Process of simple sentence comprehension of mentally retarded individuals. *Japanese Journal of Educational Psychology*, **37**, 117-125.

Matsumoto, T. and Furutsuka, T. (in press). Two stages of in sentence comprehension process in mentally retarded individuals. *Japanese Journal of Special Education*.

Suzuki, J. (1977). Lexical ordering strategy in early Japanese children. *Japanese Journal of Educational Psychology*, **27**, 56-61.

EARLY INTERVENTION FOR CHILDREN WITH DEVELOPMENTAL DISORDERS WITH EMPHASIS ON THEIR RELATIONSHIP WITH CAREGIVERS

Takashi Furutsuka
Hokkaido University
Yuki Tanaka
Portland State University

In 1982, the first author began to conduct on an intervention program for disabled children including autism and mentally retarded children aged from two, at Research and Clinical Center for Child Development in Hokkaido University (The program will be referred to RCCCD program). Their mothers also participated in this program. Since the children were so young, some children in a "gray zone", not yet clearly identified as disabled, were included. As a result, some of them were proved not to be "disabled". These experiences helped us to understand the development of children with disabilities as well as normal children. Especially, we have learned the more sophisticated and more detailed processes of development. Based on these experiences, we identified four propositions regarding early intervention programs.

Proposition 1. Enriched Environmental Stimulation

No parents expect their child to be born with disabilities. Thus, the facts that an infant has any delay in development impacts on the parents seriously. It also has impacts on the parent's stability of mind. Sometimes, it takes several years until they can accept the reality that their infant was born with disability. During these periods, they may not be able to provide enough care for him, especially providing adequate environmental stimulation such as emotional, cognitive and social stimuli. Stern (1985) stated that in order to provide enough interactions with their infant, the caregivers need to have stability of mind and a feeling of happiness about their life. The caregivers of the children with disabilities also must keep these status of mind on caregiving, even if they are beginning to be aware and anxious that their infants has disability. At this age before two, it is important for parents to decide that caregiving for the infant is the primary concern, and solving their own problems (i.e. denial, grief or despair) is a secondary problem.

Generally, parents need to have some visible evidences to accept the disabilities

This report was written when the first author spent his sabbatical leave in Portland State University, Oregon, U.S.A. I thank Drs. Ruth Falco, Joel Arick and David Krug, for discussions about the intervention described in the paper. I also thank all the colleagues in PSU whose kindess made my stay a fruitful and a memorable one.

of the infant. In the cases of cerebral palsy and Down's syndrome, parents can realize and accept the child's disability at an early age, since these disabilities are evident. On the other hand, the parents, who have an infant with autism or mental retardation, may take a longer time to accept the disability and to discuss how to change their situation for better development. One day, they focus the facts of development and neglet the delay. Another day, they find the facts of disabilities and worry about them. The more supportive evidences of his normal development they have, the more time is needed to accept their infant's disabilities. According to Furutsuka's Inventory of Parents who had an infant with disabilities, most found some delays in sensory motor and emotional developments at the age of six months. Thirty five percent of parents reported that they had some evidences of disabilities by one and half years old. Most parents still have a hard time accepting these facts. It usually takes around three years after the birth of the child for their parents to reach a point of acceptance and readiness to discuss the preferred methods of parenting. During this period, the study at the RCCCD indicated that parents took the following three major attitudes in parenting behavior (Furutsuka et al. 1993).

1 Inappropriate Emotional Interaction

There was less appropriate emotional interaction between the parents and infants with disabilities. Although there was interaction, they interacted in an inappropriate manner, such as negative or neutral emotional expression to the infant's positive emotional activity (i.e. smiling to mother). These attitudes may exacerbate delay of development.

In order to change these attitudes, the RCCCD program offered counselling for the parents, focusing on their own problems such as their distress. However, the change of their attitudes was impossible without any change in development of their child. Based on this problem, the program focused on the facilitating the development of their child. Therefore the program was designed to counsel parents regarding problems in parenting their child.

To facilitate their infant's development of emotion, as well as cognitive development, it is a critical factor for the parents to have stability in their own emotions and responsiveness. Specifically, it is necessary to provide consistent emotional response to specific child behavior, because the infant learns and socializes his emotional expression through the interaction with his parents, especially during the first two or three years of life. For example, we found that one autistic child had a tendency to smile when she felt some anxiety, and to show aggressive behavior (i.e. punching or pushing to others) as a greeting ("nice to meet you"). Therefore, it is important for the parents to understand their infant's emotion correctly, in spite of the peculiar expression, and then, to modify them to socially acceptable expresssion. Consequently, the parents need to provide various emotional expressions consistently and continuously, in their interaction with their infant. Researches of social referency reported that the infant decides the appropriate emotion for a particular context through reference to his parents' emotion (Campos and Sterberg, 1981).

2 Inappropriate Demands

When parents feel anxiety over the disabilities of their infant, they tend to give developmentally inappropriate demands. Specifically, the demand is too easy or too difficult for the child to perform.

These parental attitudes were called "ambivalent type", either "overprotective" or "constant punishment or correction". Both attitudes suppress the infant's developments.

When given too easy demands, the infant has less motivation to do any task, which delays his development, especially in self help activities. On the other hand, when the parents give too difficult demands or tasks, the child cannot accomplish their demand. As he fails, parents punish or correct his activities and then to the parent becoming angry. From the parental point of view, there is sufficient reason for punishment. At the point of children, punishment occurred because the parent gave too difficult demands. It leads the infant to feel helplessness and apathy, or to exhibit aggressive or self injurious behavior. As it were, the parent and the infant have some reasons to justify their behavior. Ideally, the demand should be set a little higher than the infant's current developmental level, which infancy indentified as "optimal discrepancy hypotheses" in setting these demand (Kagan et al., 1978).

3 Ignorance, refusal, or Exaggerative Response and Deprivation:

Parents' anxiety of having a disabled infant causes another response, ignorance, refusal or exaggerative response. Therefore, the infant cannot receive or obtain any consistent response to his specific behavior, so he can not associate his behavior with his parent's response. Lack of contingency causes no learning. The parent's consistent response to infant's specific behavior is an essential factor for cognitive development. These three major attitudes can deprive sensory, social and cognitive stimulations from the infant with disabilities, especially, under one year old.

In order to avoid these deprivation, it is important to follow three stages of the ideal course of parents infant interaction: ① the parents imitate or follow the infant's behavior, ② they modify these imitation, to highlight specific parts of task, and to elaborate new skills in the chains of reciprocal behaviors, and ③ the parents lead the infant to understand how to think, what is important, and what style of expression is socially acceptable.

These conditions are indispensable for the development of the children with disabilities. Through our intervention programs, it was found that the development of disabled children is facilitated most effectively by these methods. Also, this method can be most effective when the infant interacts with the the person whom he regards as a secure base (mother, father or grandmother).

Under normal development, infants make attachment to a specific person, and fear strangers at around a year old. In other words, he selects the caregiver as the reference of his behavior, especially social behavior. For example, when he cannot decide how to behave, he imitates the behavior of this attached person. As it were, he can interact, at an appropriate developmental level, with only this specific person, but with the other persons he can not interact appropriately, because stangers do not

behave specifically according to his specific expectation. As result, he feels anxiety toward a stranger as called "8 months anxiety or 12 months anxiety" (Spitz, 1950). But it is important to understand that this behavior is brought not by his fear or anxiety but by discrepancy of his expectancy. We found that disabled children making attachments to specific persons more strongly than normal infants. Since their flexibility of behavior is restricted, the separation from the attached person caused more severe behavioral dysfunctions.

After children with disabilities have acquired the attachment person, only the attached person can use behaviors (praise, scold) as social reinforcements.

In summary, to use these methods effectively, it is too late to begin intervention after parents accept the fact of their infant's disabilities. Even if during they are still uncertain and confused, the improvement of the interaction between parents and infant must be started.

Proposition 2: Plasticity of Brain and Constraints of Environmental Stimulation on Development

In 1936, Kennard studied the effects of resections of motor cortexes of rhesus monkey on their behaviors. A monkey who was sectioned early, recovered to walk and feed by himself. On the other hand, a monkey that was damaged after adulthood did not recover to walk. This phenomenon is called "sparing". Namely, the repair of neuronal function occurs when the brain is injured early in life, but when injured later, they can not recover the function. Also, it is well known that some children with damage in the left temporal language area showed recovery of language function. Researchers have reported that patients whose brain was demaged in childhood showed the recovery on various kinds of functions. The "sparing" has been identified as the "Kennard Principle" (Kennard, 1938).

The basic assumption of the Kennard Principle is that all areas of the brain have functional equivalence, which is changeable to the center of any function when young, and exercise makes the localization of some function (e.g. language). Therefore, if the damage occurs before localization is determined, the neighboring areas or another hemispheric areas which correspond to the damaged area substitute this damaged function. If this principle is correct, persons who concern the children with disabilities (parents, teachers and others) can hope for the recovery of children with disabilities.

After the decade of the 70's, it became evident that the Kennard Principle has many restrictions. New trends of research developed a theory of the "plasticity of the brain". The "plasticity of the brain" means that brain have self repairing functions and can construct new neuronal circuits if innate circuits were damaged. Being different from the "Kennard principle", plasticity has the restriction which is called the "critical period".

Researchers made experiments to answer the following questions. "After brain damage, under what conditions does the reconstruction of neuronal circuits occur? If no repair, why did it not occur?."

Several studies found that localization of various functions occurred at different ages, including the period of fetal development. For example, the localization of visual

function starts after birth and continues until one year old. On the other hand, language function has the plasticity until adolescence. When the damage occurred in the period before or during localization, the recovery of function can be possible. However, if localization is over, no recovery was expected. This sensitive period is defined as the "critical period". During this period, the organism needs inputs from external environment by which the neuronal circuits become complex and sophisticated. If deprivation of inputs occurs at this period, the neuronal circuits are in insufficient and inappropriate states.

According to the well known findings of Hubel and Wiesel (1970), the principle of a "critical period" has the validity in the domain of sensory and associative sensory cortex. They reported that when one eye of a kitten was closed off for several weeks, the receiving cells in the visual cortex did not develop appropriately. Atkinson and Braddick (1988) also reported that the unused eye of the children with strabismus became weaksight, but when the used eye was shut with an eye patch, they began to use the previously unused eye. As a result, visual acuity of the unused eye increased. However, when the eye patch was removed and the child use both eyes, the unused eye's acuity weakened again. In another words, the neuronal circuits which had been made in the critical period have better stability than those which were made after the critical period.

According to the definition of "the critical period", the environmental stimuli which were needed to make neuronal circuits for specific function, and the period when these stimuli were needed is determined innately. However, the complexity and sophistication of those circuits are operable through manipulating the quantity and quality of inputs. Disabled children have some difficulties in constructing neuronal circuits (i.e. difficulties in learning and difficulties in processing sensory input). These data regarding the "plasticity of the brain" indicate that there is a need to facilitate the development of neuronal circuits in disabled children.

For example, the sucking reflex of the infant, ordinally, works only by stimulating mouth, lips or cheeks. Through exercise, he becomes good at sucking skills, and associates other stimuli that occurred contingently with a sucking, such as mother"s face, smiling, and vocal sounds. This process is learning. There is a need to change from innate neuronal circuits to more adaptive circuits.

Children with disabilities also show some normal construction of the neuronal circuits along the above mentioned course. However, different from normal children, they have some problems. So, parents of children with disabilities need to intervene in the following two domains. Intervention is needed to repair the damaged reflex and to strengthen the reflex circuit (that is, repair of innate circuits). Intervention also needed to assist the infant to receive sensory stimuli correctly. Disabled children, especially autistic children have the tendency to avert overstimulation or affective stimuli. Parents should understand this is not an aversion of themselves but the results of the dysfunction of neuronal circuits for sensory information processing.

If they interpret the behavior of the child as aversion to them, parents will not interact with their infants. But understanding the behavior as resulting from overstimulation, they can strengthen sensory processing with interactions at the appropriate

level of stimulation.

According to the studies of development, various kinds of functions have critical periods within the first two years. Each function needs specific experimental stimuli to construct its own neuronal circuit. These needs cause difficulty in intervention. Along with understanding these needs, professionals, and parents too, must work to facilitate these children's development with effort and endurance.

Propositon 3: Difficulty of Motivation

The most difficult problem in rearing children with disabilities is to motivate them to do tasks. In most cases, although the caregivers give stimulation (tactile, auditory or visual) to their infant, he shows no interest or avoids the stimulation. However, stimulation is indispensable to the development of children with disabilities. In order to maintain sensory stimulation, the caregiver usually needs feedback from the child, such as smiling or getting his attention. Usually, if caregioers guess that the child has not an interest, they try to give another stimuli to motivate him. However, they often receive no feedback from the child with disabilities, so finally they feel that their devoted efforts are fruitless. As a result, they abandon giving sensory stimulation.

In additon to their lack of responsiveness to sensory stimulation, children with disabilities generally have a tendency to be unresponsive to any task. Consequently, there is doubt as to whether there is impairement in their mechanism of motivations.

Theoretically, "motivation" or "drive" means the mental condition in which an organism feels absence of something needed or desirable, and is searching for satisfaction (Hebb, 1972).

The mechanism of motivation consists of two subsystems. One is the arousal system and another is the limbic system. The arousal system supports the cortical process, like gas for a car. On the other hand, the limbic system is regarded as the centers of the motives (the center of hunger and satiation is in the hypothalamus, and the center of emotion such as fear and pleasure is in the limbic system).

Als (1982) recorded the infant-mother interaction with VCR and studied differences in the interaction among normal, severely mentally retarded, and blind infants.

In the case of normal infants, the interaction occurred appropriately. For example, when the mother did something, the baby gazed at the mother, and also, when the baby vocalized, moved or did something, the mother stayed still to receive feedback information from her baby. Sometimes they laughed together.

The blind infant and his mother, they could not interact appropriately for the first few weeks, however with intervention to the mother on how to give auditory stimulation instead of visual stimulation. Their interaction became better after one month or so. In this case, in spite of knowing her infant's blindness, the mother needed more than one month to change her parenting behaviors.

On the other hand, the interaction between the mother and infant with severe disabilities was inappropriate from the first time and the mother soon stopped the interaction, saying that she could not endure any more. The disabled infant showed over-

excitement (crying) with a little stimulation from the mother or he couldn't shift his level of arousal or activation appropriately to the mother's stimulation. Usually, when infants show over exicitation, mothers need to soothe them. However this mother did not know how to soothe her infant. His range of activation was so limited that even a little stimulation became out of range.

Stern (1985) said that infants before two months old need to learn "physiological regulation" with the help of their caregivers. The disabled infant also needs to acquire this ability. In order to acquire this regulation, the caregiver must learn how to stimulate and how to soothe her baby, specifically.

The method of maintaining appropriate level of arousal is as follows: when the infant with disability has a tendency of over activation, there is a need to give brief stimulation and stop before over activation. Even if he averts and withdraws from the stimulation for the first time, we mnst repeat stimulation and make him endure it. Finally he comes to anticipate stimulation.

On the other hand, when he shows no response, there is a need to increase the level of intensity and find the appropriate intensity, then maintain it. After the expectation of stimulation is confirmed, the caregivers can decrease or increase the level of intensity of the stimulations to extend the range of appropriate level of activation. After acquiring stability of activation level, the infant is given an interactive task. For example, in playing "peek a boo", the caregivers initiate the play, and wait for the infant's response. Even if they receive no response, they must repeat this over ten times everyday. In order to understand what happens and what result is obtained, the disabled infant usually needs several sessions of exercises. After the experience of the whole process of the play, he starts to respond with smiles and cooing. Having understood the play, he likes the tremendous repetitions.

However, the caregivers usually express dissatisfaction about these tremendous repetitions. Since the disabled infant is making the neuronal circuits of this task through exercise, the caregivers need to endure the inexhaustible repetitions and wait for habituation to occur. When the infant expects or anticipates the desired result and he has the will to acquire the desire, it is said that he is now in a state of being motivated. It is important to understand that learning leads to motivation.

Especially in caregiving for infants with disabilities, caregivers should have the attitudes to make their infant to learn motivations, rather than they search for their infant's motives (interests), when their interactions are not appropriate.

Propositon 4: Intervention Program for Children With Disabilities

The child with disabilities is ready to challenge tasks which facilitate his cognitive development when he is around two years old.

Usually he responds to the cognitive tasks in the following manner: (a) He can not understand the situation and how to respond, so he seems to be inattentive or to act on the objects with already acquired skills; (b) his attention is easy to distract by other stimuli, including reinforcing stimuli; (c) he can not focus attention on the task relevant features of the stimuli; or (d) he can not imagine what happened when the results are obtained. Namely, he can not understand the meaning of reinforcement.

In spite of these behaviors, he must acquire the attitude to solve the problems. In order to achieve this attitude, a 5 minute lesson by caregivers is developed and presented once a day at a certain time. It is important to do it only for five minutes. Also it is important that the infant has a right to stop the lesson less than five minutes if he wants. Usually, he is able to endure for 5 minutes, after several repetitions of the lesson.

The strategies of this lesson are as follows; the caregiver repeatedly shows a whole process of a task by modeling procedures. At first, it is important not to use reinforcement. Since the stimulus on the reinforcement distracts his attention. The best way is to use a peer as a task solver model. After seeing the whole process repeatedly, he is able to understand the process as a whole, especially what happens when the problem is solved.

As the disabled infant becomes interested (or motivated) in this situation, he starts solving the task by himself. At this stage, any activity needs to be reinforced. Also, the method of "shaping" should be introduced. It is important that he succeeds with 100% probability in order to keep his motivation. By decreasing the "shaping", the caregivers assure that the infant is able to perform the task thoroughly by himself. Then, the caregivers start to delay the presentation of stimulus or their response, in order to facilitate his expectancy and demanding behavior.

Based on our experiences in this intervention, this method seems to be effective. Theoretically, there are three principles to support this method: contingency, development sequence, and self-esteem.

1) Contingency as a Base of Learing.

Watson and Ramey (1969) reported that when two month old infants experience the contingency in the some activity (moving head) with the stimulus (display movements), they showed an interest on this association and responded with emotional behavior (such as smiling and cooing). Consequently, they understand the contingency of their behavior and stimulation. Many researchers think this understanding of contingency as the base of learning. The understanding of contingency begins with between motor activity and stimulus, between two external objects, and finally, between internal representations. It is called as "the association of ideas". At the middle of the second year, the normal children usually begin to imagine or represent things in their minds, and they can use signs and symbols. As a result symbolic play and language usage become possible for them.

Although disabled infants understand this contingency, they need external stimuli in constructing contingency. They usually have the weakness in representing things in mind. In order to overcome this deficits, the technique of delayed response is introduced. The disabled children showed still difficulty to make representation and to keep it in their minds for a long time.

This is the restriction of the disabled children. However, "they can feel happy when they understand the contingency".

(2) The Problems to Sequencing the Tasks for Facilitation of Development

The children with disabilities begin to enjoy the solutions of cognitive tasks. Next stage is to determine the sequence of tasks which are most effective to facilitate their development specifically.

This method is called "developmental milestones hypotheses". According to experiences in this intervention program, there is no evidence about what kinds of tasks is needed to arrive at the next milestone. As discussed in proposition 2, the children must learn many kinds of tasks simultaneously.

Hunt (1987) reviewed the effects of early experience on development. His conclusion is as follows.

"The effects of experience on the rate of early psychological development and the specific relationships between kinds of experience and kinds of developmental advance has been confirmed." Hunt, 1987 p. 44).

He selected 6 subscales from Uzgiris Hunt ordinary scale (the OBJECT PERMANENCE, MEANS ENDS, GESTURAL IMITATION, AND VOCAL IMITATION SCALES). The specific experiences which correspond to each subscale faciiitate specific development but no general development. Also, Wachs (1987) presented the "BEAM MODEL". He noted;

"A few environmental factors (i. e. contingency) have grobal effects on most development patterns for most children at most ages. The great majority of environmental factors are highly specific in their action patterns. They have the three components, such as environmental, age, and organismic (individual difference) specificities".

In general, it is very difficult to develop an intervention program for specific individual children who are over two years old, since they each have different environmental, age, and organismic specificity. Probably, there is a need to develop programs which have multiple tasks.

At this stage, it is better to present "the menu" of tasks for disabled children, so they have a right to choice what kind of task to facilitate their own development at this moment.

(3) High Self Esteem

Most studies reported that disabled children have low self-esteem and also low self confidence. Koegel and Mentis (1985) have reported that some autistic children displayed low motivation and apathy, they also suggested that these may be the indicative of learned helplessness. It has been said that children who frequently fail to accomplish the demands may develop a sense of learned helplessness.

Since the start of the RCCCD program of intervention, one of the most important propositions is that the children with disabilities should keep high self-esteem, even if they fail to accomplish their demands. One solution is to provide them experiences which are adjusted to their developmental level. Through the insurance of 100% suc-

cess, they develop a sense of contingency and a sense of control. Thus they come to have confidence of their ability. The other solution in keeping high self confidence is that caregivers do not attempt to keep the child trying to cope, if the child can not cope with the demand. Hunt (1987) said:

"When the child encounters situations with demands beyond his/her ability, these demands do not even exist as challenges. When the challenge is appreciated but the child cannot cope, he/she will, if free to do so, leave the field without damage; but if adults attempt (by means of either reward or punishment) to keep the child trying the child suffers both stress and distress and damage to his/her confidence."

According to Hunt, we can say that failure in any task does not of itself cause lowering of self-esteem, but when caregivers' demands for tasks that children cannot cope with, does do damage to their self-confidence.

There is another solution to keep self confidence high. The child with disabilities, as well as every human being, needs support from another person (attachment person, family, or teacher) and also a supportive atmosphere in their family and society, even if there is no hope in life. This is a difficult problem to treat. However, after participation in our program we can see that children with disabilities and also their parents recover their spirits and feel happy in spite of their difficult lives.

REFERENCES

Ainsworth, M.D.S., Blehar, M.C., Waters, E., and Wall, S. (1978). *Patterns of attachment: Assessment in the strange situation and at home.* Hillsdale, NJ: Lawrence Erlbaum.

Als, H. (1982). The unfolding of behavioral organization in the face of a biological violation. In E. Z. Tronick (Ed), *Social interchange in infancy: Affect, cognition, and communication.* Baltimore: University Park Press. Pp. 123-160.

Atkinson, J. and Braddick, O. (1988). Infant precursors of later visual disorders: Correlation or causalty? In Yonus, A. ed. *Perceptual development in Infancy: The Minnesota symposia on child psychology,* 20 LEA New Eousey.

Campos, J. J., and Sterberg, C. R. (1981). Perception, appraisal and emotion: the onset of social referencing. In M. E. Lamb and L. R. Sherrod (Eds), *Infant social cognition: Empirical and theoretical considerations.* Hillsdale, NJ: Lawrence Erlbaum. P. 273-314

Furutsuka, T. (1989). A proposal for early intervention based on improvement in mother infant interaction. *Bulletin for emotional disorder research and education.* Hokkaido Educational University (Asahikawa) Press.

Furutsuka, T., Aiba, Y., Ito, K. Ohta, K., Kawamorita, K., Kaneuchi, K. Satoh, M., Suzuki, M., Takechi, E. Sensu, K., Miura, T., Tatsuta, O., and Gotoh, M. (1993). The present conditions and concerns of early care in the city of Sapporo. *Journal of Normalization Research in Hokkaido,* vol. 5 p. 69-86.

Hebb, D.O. (1972). *Textbook of Psychology.* New York; Saunders.

Hubel, D.H. and Wiesel, T.N. (1970). The period of susceptibility to the physiological effects of unilateral eye closure in kittens. *Journal of Physiology* (London) **206**, 419-436.

Hunt, J. McV. (1987). The effects of different kinds of experience in early rearing conditions. In Uzgiris, I.C. and Hunt, J. McV. (eds. *Infant performance and experience: New Findings with Ordinal scales,* Unversity of Illinois Press, Urbana. 1-39.

Kagan, J., R.B. Kearsley, and P.R. Zelazo (1978). *Infancy : Its place in human development.* Cambridge : Harvard University Press.

Kennard, M.A. (1938). Reorganization of motor function in the cerebral cortex of monkeys deprived of motor and premotor areas in infancy. *Journal of Neurophysiology*, **158**, 37-54.

Koegel, R., and Mentis, M. (1985). Motivation in childhood autism : Can they or won't they? *Journal of child psychology and psychiatry*, **26**, 185-191.

Seligman, M. (1975). *Helplessness : On depression, death, and development.* San Francisco : W.H. Freeman.

Spitz, R.A. (1950). Anxiety in infancy : A study of its manifestations in the first year of life. *International Journal of Psychoanalysis*, **31**, 138-143.

Stern, D.N. (1985). The interpersonal world of the infant. New York : Basic Books.

Watson, J.S. and Ramey, C.T. (1969). Reactions to response contingent stimulation in early infancy. *Merril Parmer Quaterly*, **18**, 219-228.

Wachs, T.D. (1987). Early experience and early cognitive development : The search for specificity. In Uzgiris, I.C. and Hunt, J. McV. (eds.) *Infant performance and experience : New findings with Ordinal Scales.* Urbana : Unversity of Illinois Press.

ON THE DEVELOPMENTAL ORIGINS OF HUMAN HANDEDNESS[1]

Brian Hopkins
Free University Amsterdam

One of the oldest controversies about human behaviour concerns the origins of handedness. Many speculations have been offered, but few have withstood scientific examination. Part of the lure of this seemingly straightforward expression of the motor system is the claim that it is a uniquely human trait that is closely associated with the acquisition of language. Such claims are currently the focus of intensive programmes of research concerned with the origins of human development and evolution. With regard to the developmental origins of handedness, there are presently a number of empirically accessible models which differ from each other in important ways. In the present paper we examine the strengths and weaknesses of these models in an attempt to distil what might be fruitful directions for future research. However, before attempting this task we ask two essential questions: Why should developmental psychologists study handedness, and what is meant by handedness? We conclude by, among other things, posing a number of questions about the development of handedness that still need to be addressed by subsequent theory-building and testing. Answers to such questions will only come from process-oriented models on the developmental (and evolutionary) origins of handedness which can illustrate how early motor asymmetries may be linked to later biases in manual functions.

Key words: hand preference; manual specialization; prenatal asymmetries; headedness; primates

1. Introduction

There has been a long history of debate and research into the origins of human handedness, much of which has been captured in an excellent review by Harris (1983). In contemporary man, handedness assumes a J-shaped distribution in which 85-90% of the adult population demonstrate a right-sided bias, depending on which measures of hand use are employed. Explanations for this bias, which has been held to be culturally invariant and species-specific, have been inextricably linked with questions about the developmental and evolutionary origins of language. Both in development and evolution, it was assumed that handedness was simply an epiphenomenon arising from the acquisition of language. This assumption led to two conclusions which have been only recently challenged, namely, that handedness is late-occurring phenomenon both in development and during human evolution. These conclusions had the effect of assign-

[1] This paper is based on a presentation made at the Eighth Meeting of the Midwinter Conference on Current Issues in Developmental Psychobiology, Costa Rica, Jan 7-11th 1933

ing handedness a marginal role in the evolution and development of human abilities. More importantly, they precluded attempts at seeking empirical evidence for the origins of a distinctively human trait prior to the ontogenetic and phylogenetic attainment of language. To have admitted prelinguistic origins would have further dismantled deep seated beliefs about the unique position accorded to *Homo sapiens* in the animal kingdom. Thus, questions about the origins of human handedness are by no means trivial, but rather go to the very heart of what it is that distinguishes us from other animals. Recent answers to these questions form the focus of the present contribution. Given the enormity of the topic, its focus will be restricted to the developmental origins of handedness. However, some questions about evolutionary origins will be raised. The first question to be raised though is "Why study handedness?"

2. Why study handedness?

For developmental psychologists unfamiliar with the vast literature on handedness, it may not be immediately obvious why this behavioural trait should be of interest to them. At a general level, handedness is a readily observable phenomenon that as such enables one to address a number of the grand issues that continue to confront developmental psychologists. Such issues include gene behaviour relationships, brain behaviour relationships, constancy versus change (e.g. between pre- and postnatal life), sensitive periods and the role of experience. Given the apparently unambiguous nature of handedness, it may be possible to generate findings relevant to these issues which are generalisable, in the sense of a developmental principle, to other domains of development.

This claim is by no means new and can be found, for example, in the writings of Baldwin (1890; 1894), one of the founding fathers of contemporary developmental psychology. In studying the development of his own daughter using experimental methods, Baldwin paid particular attention to reaching and grasping and their lateralization on the assumption that they provided a window to mental development. More recently, and continuous with Baldwin's thinking, Young (1990) has proposed an ambitious theory which links the development of lateralization (mainly handedness) to a number of cognitive achievements (most notably language). Termed an inhibition theory of complementary hemispheric specialization, it results in a 20 step model of development. The basic assumption is that the cerebral hemispheres contribute differentially to processes of behavioural inhibition with the left hemisphere being the site of a sophisticated mixture of activation and inhibition which serves to control the sequencing of acts in both language and fine motor abilities. In contrast, the right hemisphere is more specialized for spatial processes and less so for any manifestations of dynamical inhibition. The question then, which remains largely unanswered in Young's theory, is what are the exact relationships between changes in the lateralization of functions and the development of cognitive abilities (which in Young's case are defined in Piagetian terms)? Are they in some sense unidirectional or bidirectional in nature? The most that can be said at the present time is that changes in the development of lateralization (and in particular handedness) appear to 'flag' new achievements in the cognitive-linguistic domain. This assertion is amply illustrated in Ramsay's (1980 a; b) pro-

gramme of research on the codevelopment of hand preference and speech. What Ramsay found were coincidences between *a*) the onsets of canonical babbling and a right-handed preference for manipulation, and *b*) the onsets of reduplicated babbling and bimanual coordination. He went on to speculate that speech production precedes the appearance of manual asymmetries at 6 months, whereas at 12 months the reverse is the case.

For the clinically oriented developmental psychologist, the development of handedness merits more than a cursory glance. Many studies have demonstrated that left-handers are clearly overrepresented in groups with severe and generalized cognitive deficits (see Pipe, 1990 for an excellent review on this topic). What is less clear is whether non right handedness is also associated with specific deficits such as reading disability, perceptual problems, stuttering and mild intellectual retardation. What is almost completely opaque concerns the mechanisms by which central nervous system dysfunctions are expressed as deviations in handedness—a situation arising from lack of carefully designed prospective studies.

The utility of handedness for addressing fundamental and clinical issues of relevance to developmental psychologists should now be clear. The outstanding stumbling block to further progress on both fronts emanates from a lack of a clear understanding of the developmental origins of handedness. Thus, the main problem to be tackled in this paper is how the right bias in human handedness could originate. To this end a number of current theories which concern this topic will be considered in terms of their explanatory vigour. Some attempt will be made at forging links between them although this will be kept to a minimum as the theories involved are, in their present states, very disparate in nature and hardly conducive to a sensible integration. However, before embarking on this task, we should realise that any attempt at explanation assumes that we have an unequivocal understanding of the term handedness. Unfortunately we do not and this constitutes a problem, namely, what are we seeking the origins of? And consequently, what is it that develops? These questions will be addressed (section 3) before discussing the theories of interest (section 4). Subsequently, a six-point summarising commentary will be given that may serve to guide fundamental research in the future on the development of handedness (section 5). With a similar intention, the paper ends with a number of questions (and some tentative answers) that are ordered in terms of what I consider to be their relative importance (section 6).

3. What is handedness?

It is becoming clear that handendness is a multidimensional, rather than a unidimensional, trait. It can no longer be conceptualised as a rigid reliance on one side of the body regardless of the task conditions. At the very least we need to make a distinction between hand preference and manual specialization (Young et al., 1983). Accordingly, hand preference can be defined as the consistent use of one hand on simple and familiar tasks and manual specialization as lateralized usage on more complex, less familiar tasks which may involve either hand. In terms of development the relevant questions are then: how does a hand preference originate and how does it relate to later occurring forms of manual specialization? To examine such questions requires

assessments of hand use across a range of tasks at different ages, something which is hardly done in studies on infants. One of the few studies to do so was carried out by Michel et al. (1985). Here 12 infants at each month from 6 to 13 months (thus 96 in total) were examined on three different tasks (reaching for objects, manipulating objects and carrying out complementary bimanual actions). At all ages, the right hand was preferred for manipulation, as it was for reaching, with the exception of 13 months. Bimanual manipulation (which is evidence of manual specialization in that one hand manipulates the object while the other supports it) was not clearly evident until 12 months. Once again it was mainly the right hand that did the manipulating. At 13 months, most of the infants' preferences during reaching and bimanual manipulation were no longer compatible. By this age it appeared that the nonpreferred hand reached to and secured the object so that the preferred hand could then manipulate it. Thus, by using a variety of tasks, it was possible to arrive at the conclusion that a right-sided preference for reaching at 6 months of age is incorporated into more complex abilities at later ages. If only reaching had been used as an index of handedness, then hand preference would have appeared to fluctuate during the second half of the first year.

What is known about the development of handedness during the first half of the first year? Here the picture is less clear with evidence for a consistent righthanded preference (Michel & Harkins, 1985) as well as for fluctuations between hands across age (Carlson & Harris, 1985). At the root of these differences in findings is whether a left hand preference appears before a rightsided one. Both Gesell and Ames (1947) and Seth (1973) reported that reaching initially showed a leftsided bias, but these studies were subsequently criticized on statistical and methodological grounds (Young, 1977; Annett, 1978). More recent and better controlled studies provide conflicting findings. Some have reported an intial rightsided preference (von Hofsten, 1982; Young et al., 1983) and others a leftsided bias appearing before or at about 3 months (Coryell & Michel, 1978; DiFranco et al., 1978; McDonnell, 1979). A similar lack of correspondence has been found between studies on grasping a rattle placed in the hand. Three found a righthand preference around the same age (Caplan & Kinsbourne, 1976; Hawn & Harris, 1983; Petrie & Petes, 1981) while a fourth could not find any bias (Yu-Yan et al., 1983). At the present time the most we can conclude is that the earliest signs of hand preference appear to be task-specific in that they are dependent on whether the task involves control of the proximal muscles (as for reaching) or the distal segments of the hand (as for grasping). Furthermore, it may be questioned whether reaching before 3 months, which does not involve prehension, should be used as an index of handedness. It seems more appropriate to treat it as an indication of arm preference and then to ask how it can be reconciled with a hand preference for grasping.

All of the above lead to the following conclusions. Firstly, better definitions and more precise measures of handedness are needed. Secondly, the use of a variety of measures of handedness that can account for developmental changes in manual abilities. Thirdly, the need to incorporate the emerging abilities of the nondominant hand into the definitions and measurements of handedness. Fourthly, to pay more attention to

individual differences, for example, through using the distinction between the direction and degree of handedness. Few studies on the development of handedness in human infants appear to have given consideration to all these points. In these respects, we have much to learn from recent investigations of hand use in nonhuman primates (e.g. Hopkins, W.D. et al., 1989).

4. On the developmental origins of handedness

There is a plethora of speculations on developmental events that may lead to a righthanded bias in humans, many of which have a long history (Harris, 1983). In the last decade a number of these speculations have been reworked into testable models. For the present purposes they will be termed the biased oocyte, the biased gene, the biased brain, the biased head and the biased uterus. Each of these models has its own idiosyncratic shortcomings which mitigate against a comprehensive model on the developmental origins of handedness. However, where possible, points of contact between these models will be indicated.

a. *The biased oocyte : the left right maturational gradient model*

According to this model, lateral asymmetries such as handedness are governed by a left to right maturational gradient coded in the spatial structure of the unfertilized egg rather than in the genes (Corballis & Morgan, 1978). It is based on the fact that all living cells have intrinsically anymmetrical properties. What is unique to this model is that it incorporates maternal effects that do not rely on a strict genetic interaction between mother and father. Accordingly, the gradient is laid down during oogenesis by factors intrinsic to the cytoplasm and not to the nuclear genes. However, the actual expression of an asymmetry ultimately depends on genetic and environmental influences.

The shift from an initial left to a righthand preference may be related to this gradient, but as we have seen, there is contradictory evidence as to whether functional development begins with a sinistral bias. As we shall see, there are cerebral asymmetries which do not perfectly correlate with hand preference as would be predicted if both were based on the same maturational gradient. Furthermore, embryological evidence supports neither a left right or right left gradient, but rather suggests cyclical or fluctuating asymmetries during growth (Mittwoch, 1978). The main stumbling block for this model is, however, the lack of evidence that cytoplasmic inheritance plays a role in vertebrates. On the contrary the inheritance of lateralized traits is through the nuclear genes. Thus, if there are maturational gradients underlying the origins of handedness, then they should be under some form of direct genetic control. This is assumed in the most widely accepted genetic model of handedness which we turn to next.

b. *The biased gene : the right shift gene model*

Proposed by Annett (1985), this model stresses that handedness is not a discrete variable but one with a continuously varying gradient. Thus, there are degrees of preference which are systematically related to a continuous distribution of differences between the hands in the performance of particular tasks. The model has two compo-

nents: one genetic and the other environmental or more properly accidental in nature. The majority of individuals inherit a gene which predisposes them to left hemisphere control of speech and as a by product a righthanded preference. A minority of individuals lacking this right shift factor will have their cerebral dominance for speech and hand preference determined at random. Accordingly, for these individuals there is an equal likelihood that they will have a left or righthand preference, and in these cases a dextral bias can arise from environmental pressures. Thus, unlike the two gene model of Levy and Nagylaski (1972), which assumes two directional alleles, Annett's more probabilistic model can account for the high percentage (60%) of right handedness with two left handed parents. Despite such predictive power, it should be borne in mind that the right shift gene model rests on an assumption that has neither theoretical nor empirical support, namely, that both dominant and recessive alleles are present in the population at a frequency of 50%.

The importance of Annett's model for the present purposes is that it directs attention to the neglected role of familial handedness in the development of hand use. The findings of one study that included this factor complied in part with the predictions of Annett's model while at the same time stressing the need to account for the ways it may interact with the sex of the infant (Carlson & Harris, 1985). Using a longitudinal design, it was found that familial righthanded (FRH) boys and girls showed an increase in rightsided reaching from 24 to 52 weeks. However, from 27 weeks onwards, the FRH boys had a left arm preference, but by 52 weeks no lateral bias. In contrast, neither FLH boys nor girls had a lateral preference at 24 weeks, which was then followed by a right to left trend up to 52 weeks—this shift occurring earlier in boys. These findings run counter to any notion of a simple maturational gradient and cannot be straightforwardly reconciled with Annett's model (in particular those concerning FRH boys). On the other hand, the fluctuating trend manifested by the FLH group is in accordance with the model as presumably these infants lacked the rightshift gene and were therefore more susceptible to variations in environmental influences. While this study was not concerned with the developmental origins of handedness, it clearly points to the need for including both the sex of the infant and familial handedness in addressing this issue.

The data Annett has gathered in support of her model are based on children older than two years and adults. To constitute a valid model for the developmental origins of handedness, then it should be able to account for the distribution of structural and functional asymmetries during early development that have been proposed as precursors for the establishment of handedness.

c. *The biased brain model*

Many gross neural asymmetries have been found to be evident as early as the second trimester of pregnancy. However, it is unknown whether they arise during embryogenesis or during later stages of brain development (viz. during neurogenesis, neuronal migration and maturation). The processes by which such asymmetries arise are also poorly understood: do they reflect suppression of development on one side, an enhanced development on the other or a combination of both processes? According to

the neuronal loss hypothesis (Galaburda et al., 1987), the cortical hemispheres initially have an equivalent rate of development followed by involution on one side. Thus, there is an initial period of symmetrical neuronal (over) production of neurons, axons and synapses which are then pruned down more on one side by trophic factors and activity leading to that side becoming smaller. This hypothesis is not easy to relate to what is known about cerebral asymmetries that appear during fetal life. Structures such as the Sylvian fissures and the planum temporale are larger on the leftside. Other evdience points to an initial rightsided bias: from 10 to 40 weeks, it was found that the development of presumptive language areas such as the supramarginal, angular and transverse temporal gyrii was more advanced on the right side (Chi et al., 1977). In addition, the Rolandic fissure on the right became convoluted some 3 weeks earlier than its homologue on the leftside. Thus, the most one can draw from these findings is that some parts of the right hemisphere initially develop faster, but that there is later a catch-up in growth for the left hemisphere which eventually becomes the larger of the two. While this could be taken as support for an initial leftsided bias in reacking, it is highly questionable whether there are any contralateral cortical fibres that are functional when this action appears for the first time. In fact, assessments of local metabolic processes in the neonatal brain by means of Positron Emission Tomography have demonstrated little or no functional activity in any neocortical structure (Chugani & Phelps, 1986).

It is doubtful whether all the evidence for the existence of such prenatal cerebral asymmetries will help us to understand the origins of handedness. What we need is more information about the development of asymmetries in structures known to be involved in motor control, particularly at the subcortical level. A recent study of 18 normal brains, some of them as young as 28 weeks gestation, revealed the globus pallidus in the basal ganglia had a larger volume on the left side. This asymmetry was found in all brains younger than 4 years (Kooistra & Heiman, 1988). While it would be tempting to associate this asymmetry with an initial rightsided bias in reaching, it should be remembered that the basal ganglia do not have direct connections with nuclei or cortical regions which give rise to motor pathways projecting directly to the spinal cord. Furthermore, the precise role of each nucleus of the basal ganglia is currently a controversial topic.

In terms of the descending motor systems, it is known that the ventromedial system, which includes the vestibulospinal tract, develops earlier than the direct corticospinal system (Kuypers, 1985). As for the rubrospinal tract of the lateral brain stem system, it is unknown if it has any function in humans. The vestibulospinal tract projects bilaterally to the spinal cord and controls the proximal muscles of the arm. Thus, when reaching first appears it would involve ipsilateral control. Depending on which hemisphere is functionally more mature at this time, there could be either left- or rightsided biases in reaching. Individual differences in this regard could explain why there is a lack of between-study agreement on whether the first reaching movements are left- or rightsided. In the direct corticospinal system which provides contralateral control of the fingers, it is known that in the fetus most fibres of the pyradimal tract decussate more completely from left to right than the other way round (Yakovlev &

Rakic, 1966). Thus, it is possible that corticospinal fibres destined to innervate the small muscles of the right hand may be more numerous than for the left. This finding may provide one explanation why most infants display a more consistent rightsided preference after about 6 months as assessments then are derived from the ability to combine reaching with grasping. However, this suggestion only accounts for dominant hand use and not for the superiority of the left hand in visualspatial abilities. The main point is that assessments of handedness involving goal directed arm movements will be based on different motor systems at different ages. The question then is how a bias in the ventromedial system may induce one in the corticospinal system.

The models considered so far are essentially predictive in nature—biases in maturational gradients, genes or fetal brain structures should portend an ultimate right-handed preference in most individuals. They have little to say about the processes that lead to the establishment of a dextral preference in contrast with the last two (interrelated) models.

d. *The biased head and uterus models*

A number of studies have demonstrated that the orientation of the newborn's head in supine has a similar dextral bias to that found for adult handedness. The same neonatal bias has also been found for head turning when it is released from a midline position. Previously the lateralized head position adopted by the young infant was purported to be a by-product of the Asymmetric Tonic Neck (ATN) reflex (Gesell & Ames, 1947). This is clearly not the case as a spontaneous ATN position only becomes dominant at about 3 months (Touwen, 1976). Thus, the question of interest is whether the neonatal head position preference, and not the direction of the ATN position, is predictive of handedness at later ages in infancy. This question has been addressed in a series of studies by Michel and colleagues. In general, both the assumption (Michel & Goodwin, 1979) and the maintenance (Goodwin & Michel, 1981) of lateralized head position predict the arm that will be used for reaching. Subsequently, it was shown that these early functional asymmetries provided predictions of hand preference at 60 (Michel, 1981) and 74 weeks (Michel & Harkins, 1986). Michel offers a plausible and testable explanation for how 'headedness' may be related to later manual specialization. The basic idea is that the neonatal head orientation induces a lateral asymmetry in hand regard and activity in the first couple of months. Greater experience of one hand leads to it being preferred for visually-guided reaching which in turn ensures that it will become specialized for fine motor abilities. Thus, as each functional asymmetry appears it is transferred to a subsequent ability, not because each asymmetry stems from a common neural mechanism, but because there is a continuity in experience of using one hand rather than the other. The developmental origin of righthandedness is to be found in the head position preference of the newborn. What then is the origin of this neonatal asymmetry in function? One suggestion has been the position of the fetus in the last few weeks of pregnancy.

Two thirds of the fetuses born in a left vertex presentation have their backs towards the mother's left side some 3 to 4 weeks prior to fullterm delivery. In this position, with the rightside of the head facing outwards, movements of the left arm (as

well as its arterial blood) are restricted by the pelvis and backbone of the mother. Given the close relationship between head position at birth presentation and its position in the weeks before in most fetuses, it was asked if the former predicted 'headedness' after birth (Michel & Goodwin, 1979; Goodwin & Michel, 1981). It was found that a left vertex presentation was significantly associated mith a rightsided head prefemence. This was not the case for those newborns with a right vertex presentation: their preferences were randomly distributed rather than leftsided as predicted—an indication that these infants may have had a history of FLH.

Why do most fetuses assume a lateralized position with the rightside of the head facing outwards? The plausible answer is that this position is an adjustment of the growing fetus to asymmetries in the uterus. In most cases, the uterus has a torsion to the right resulting in the maternal bladder and rectum as well as the placenta being positioned to the right. Under these conditions, there is more room for the head and body on the left side of the uterus when the fetus assumes a left vertex position. Why this position should be associated with a head position preference to the right postnatally has recently been addressed by Previc (1991) in his vestibular dominance or left otolithic dominance hypothesis.

According to this hypothesis, vestibular lateralization may arise from the asymmetrical position of the fetus during the latter part of the final trimester of pregnancy. In the left vertex position, the forward acceleration and the backward inertial force generated by maternal walking would be preferentially registered by right and left sides of the vestibulum respectively. In short, when the mother walks there is an unequal shearing of the hair cells in the two otoliths of the fetus resulting in a left-otolith dominance. Impulses from the maculae of the utricles travel centrally to the brain stem and cerebellum. In the brain stem they terminate on the vestibular nuclei, one of which (Deiter's nucleus) is the origin of the vestibulospinal tract. Almost all the fibres of this tract are uncrossed and most end on interneurons in the spinal cord. The main function of this tract is the ipsilateral control of extensor muscles. For head turning, the most important muscle is the bilateral sternocleidomastoid—the left of which is activated when the head is turned to the right. Thus, a left-otolith dominance should be related to a left-sided bias in the activation of this muscle and thereby a rightsided head preference.

Previc's general theory successfully disassociates questions about the developmental origins of handedness from those about language. He does so by proposing independent mechanisms for the origins of a rightsided motor dominance and a right-ear sensitivity. In this respect alone, Previc's intriguing theory represents a considerable advance on previous attempts to link prenatal neural asymmetries with the developmental origins of handedness. We are now in a position to make cross-species comparisons as a means of addressing how a dextral bias in handedness could have arisen in hominid evolution without getting this issue confused with that pertaining to the evolutionary origins of language.

Summarizing comments

1. The measurement of handedness during infancy should take account of rapid

changes in motor abilities. There is no single task (e.g. reaching) that will provide a valid index of handedness even during the first year.

2. During the first half of the first year, it may not be hand preference that is being measured, but rather arm preference.
3. The question of whether the initial arm preference for reaching is right or leftsided is still unresolved. As such, it stresses the need for including measures of familial handedness. Should these measures be derived from questionnnaires or direct tests of handedness and should they then be treated as a binary or continuous variable?
4. Of all the models discussed, only Annett's single gene model provides a reasonable prediction of those individuals who will be right *or* left handed. However:
5. We still lack a satisfactory process oriented model for the developmental origins of handedness and for how early motor asymmetries are linked to a later bias in handedness. What should be clear is that there is no common neural mechanism which is shared by earlier and later motor asymmetries.
6. We badly need comparative primate studies on the development of motor asymmetries. These should include ultrasound recordings of fetal movements and posture in the great apes.

6. Questions (and some answers)

In answering some of the questions I will draw on published and yet to be published findings from the Amsterdam Laterality Study (ALS) currently being carried out at the Free University.

The Big Ones

1. What are the problems confronting current models on the developmental origins of handedness?

I will only deal with two here: those subscribed to by Michel and Previc.

a. *Michel*: differential visual regard of the hands arising from a lateralized head position is proposed to lead a biased use of one hand in such actions as reaching. There are two problems with this proposition. Firstly, congenitally blind individuals have a righthanded bias in reading braille (Bradshaw et al., 1992). But this is only one task which may be subject to teaching strategies biasing the right hand. Difficult though it would be, what is needed is a longitudinal study of infants blind at birth. Do they show a rightward head position preference? Do they initiate reaching with the right or left arm to an auditory stimulus? Secondly, a lateralized head position lasts only for 2-3 moths and then is replaced by a preference to hold the head in the midline (Hopkins et al. 1990). Unless we propose a sensitive period hypothesis (which is not supported by the findings on blind patients), then this seems to be an inordinately short space of time in which to establish a rightsided dominance in subsequent motor abilities. Perhaps there are other asymmetries in the spontaneous movement repertoire that persist beyond the age when a head midline position becomes dominant. We found that in newborns one hour after birth, hand mouth (but not hand face) contacting was highly lateralized (Hopkins et al. 1987): all newborns contacted the mouth with the hand ipsilateral to the

head position and most did it with the right hand. After 6 weeks this synergy breaks up and the infant is just as likely to contact the mouth with the right or left hand. However, by 18 weeks we noted the reestablishment of a right hand preference, but now with the head in the midline (Hopkins, Savelsbergh & Butterworth, submitted).

b. *Previc (1991)*: he concludes that "... the origins of vestibular asymmetry in man lie in a *neural* rather than structural imbalance favoring the left utricle" (p. 318). What is known about the development of the vestibular system suggests otherwise. The system is structurally mature very early in prenatal life (Humphrey, 1964). Despite this fact, there is no evidence that it is functional before birth. Experimental work with guinea pigs has revealed that the system is functionally inhibited by low levels of oxygen tension as experienced in utero (Schwartze & Schwartze, 1977). In the human, shaking the maternal abdomen from side-to-side failed to change the heart rate pattern or induce movements in the near term fetus which would be expected if the vestibulum was functional prior to birth (Visser et al., 1983). It is unlikely, therefore, that movements of the endolymphs and hair cells in the vestibulum of the fetus will be registered centrally in terms of action potentials. All of this suggests that a structural imbalance may be induced by the differential stimulation of the two otoliths which then exerts its neural effects after birth. Findings on preterm infants are relevant to Previc's hypothesis. In the ALS project we have recently found preterm infants born before 32 weeks gestation demonstrated a rightsided bias for the maintenance, but not for the assumption, of a head position at 35 weeks (Geerdink, Hopkins & Hoeksma, 1993), a finding in agreement with other studies (e.g. Gardner et al., 1977). It is difficult to know how to reconcile these differences in performance with Previc's hypothesis.

c. *Michel & Previc*: both models can account for the origins of right- but not leftsided motor asymmetries. Previc (1991) does try to redress this problem in suggesting... "a greater percentage of lateral positioning reversals prior to birth among sinistrals" (p. 301, footnote 3). I know of no evidence to support this suggestion. A recent study observed thumb sucking in the fetus using realtime ultrasound recordings on the assumption it may be a precursor of handedness (Hepper et al., 1990). In 274 fetuses there was a clear bias for sucking on the right thumb as early as 15 weeks of gestation which was hypothesised to be related to head turning after birth. There was no relationship found betwen intrauterine position and thumb sucking preference. Of 28 right thumb suckers, 23 turned to right and for the four left thumb suckers, 3 had a left and 1 a right turning bias. Thus, it was concluded that thumb sucking initiates development of brain lateralization. The challenge of the study is that if the fetus sucks the right thumb, then the theoretical link between 'headedness' and handedness may reside in a more fundamental asymmetry which appears many weeks before a lateralized fetal position. The limitation of the study is that it included only 4 left thumb suckers. In addition, we have found in the ALS that it is very difficult to observe thumb sucking in the fetus on a regular basis, and due to the 2-dimensional image of the fetus there are problems in arriving at reliable estimates of whether the right or left hand is

involved. However, we have been able to observe a lateralized head position appearing at 36 weeks gestation (van Gelder, Dijkman, Hopkins, van Geijn & Ho-Meau-Long, 1990; Ververs, de Vries, van Geijn & Hopkins, 1992). Before that age the head was predominantly in the midline position. Given that preterm infants also show an asymmetrical head position preference for the first time at around this age, it clearly indicates that this postural bias is due to neural maturation and not to mechanical influences emanating from uterine asymmetries. It is interesting to note that the appearance of a lateralized head position coincides with the appearance of stable behavioural states (Nijhuis et al., 1982).

2. What is the clinical relevance of research on early motor asymmetries?

There is a predilection among developmentalists to seek for stability in behavioural development. It is becoming clear, however, that intraindividual variability may be a cardinal feature of normal motor development (Touwen, 1978). Handedness appears to fluctuate, particularly during the first 6 months. For 'headedness' there are too few longitudinal studies to know with any degree of certainty whether it is also a fluctuating asymmetry within individuals. In the ALS, we have observed some degree of stability in a lateralised head position preference up to 3 months (Hopkins et al., 1990), but a high degree of variability in hand mouth contacting across the same age range. The point to be made is that a strongly lateralised asymmetry to the left *or* to the right for either 'headedness' or handedness may be indicative of underlying neuropathology. This view is in contrast to those models proposing that leftsided asymmetries, or a lack of asymmetrical behaviour, may constitute a pathological state (Bakan, 1971; Satz, 1972).

3. What do we need to know from the fossil record to help us better understand the evolutionary origins of handedness?

Endocranial casts of KNM-ER 1476 (a Homo Habilis specimen) dated at 2 million years BP have revealed left hemisphere asymmetries (Tobias, 1981). Analyses of artifacts (viz. flakes produced from knapping stone tools indicate hominids had become righthanded at about the same time (Toth, 1985). However, if the attainment of an upright posture was the prime mover for the appearance of manual specialization in hominid evolution, then handedness may have an even greater evolutionary age. The oldest fossil hominid is Australopithecus afarensis which has been dated at about 3.5 million years BP. The morphology of the pelvic girdle clearly indicates an upright posture and the ability for bipedal locomotion. What is not known is whether this hominid possessed manual specialization. The hands are intermediate between contemporary humans and chimpanzees and would have permitted a range of precision and power grips, but probably not a fully abducted pincer grip – however the latter does not necessarily exclude the potential for manual specialization. Thus, the evolutionary depth of handedness is still a matter of debate, although it now seems evident that its evolutionary appearance preceded that for language.

It would be interesting to know from the fossil record when the first evidence

for a lateralized fetal position appeared. Would it have been a left vertex position? Did it precede handedness or did they evolve together? The pelvic girdle of Australopithecus afarensis has a humanlike shape, including an oval inlet. While this does not necessarily imply a lateralized fetal position towards the end of pregnancy, some physical anthropologists contend that rotation of the fetus and flexion of its head would have been required to pass through the birth canal (Berge et al., 1984). Among primates, this mode of delivery is found only in humans. Until someone investigates whether there are asymmetrical markers in the pelvic girdles of australopithecines, we will not know whether these hominids also had another obstetrical feature in common with man, namely, a fetus who adopted a lateralized vertex presentaion.

4. Can we categorically deny that nonhuman primates do not have a righthanded bias for handedness?

The short answer is "no". The long answer is less categorical. It is generally held that primates and mammals have a preference for one hand or paw over the other, but that only humans manifest a population bias in favour of one hand. Evidence for and against this view is, to say the least, contradictory. After reviewing many studies involving prosimians, New and Old World monkeys as well as the great apes, MacNeilage et al. (1987) concluded: a leftsided bias for reaching (particularly in prosimians and New and Old World monkeys) and righthandedness for manipulation (in some monkeys and apes, but not prosimians, i.e. in those with opposable thumbs). One of the problems with the literature on handedness in nonhuman primates is the lack of studies involving the great apes. It may be the case that the most consistently righthanded great ape is the gorilla who is also the most terrestrial of them (Bresard & Bresson, 1987; Fischer et al., 1982). The best controlled study I have come across involved 2 rhesus monkeys and 3 chimpazees (Hopkins W.D. et al., 1989). Both species showed significant righthanded preferences in manipulating a joystick, but neither did in reaching for an edible reward. The biggest stumbling block in arriving at any firm conclusions about handedness in nonhuman primates is the small number of subjects involved in the majority of studies. This calls for a multicentred programme of research involving the same methods and the same definitions of handedness designed to test the MacNeilage et al. hypothesis across a range of primate species.

Because of a leftsided preference for cradling infants in humans (on the understanding that it enables the right hand to be used for manipulative activities associated with child care), the presence of this phenomenon has been sought in other primate species. Two studies found a leftsided bias in the gorilla (Fischer et al., 1982; Manning & Chamberlain, 1990), one of which also reported the same for the chimpanzee and orang utan (Manning & Chamberlain, 1990). Once again the number of subjects involved was small. In collaboration with Herman Dienske of the TNO Primate Centre, Rijswijk, we repeatedly observed nine pairs of chimpanzee mothers and their infants (Dienske & Hopkins, submitted). No significant lateral cradling preference was found although there was a tendency for a rightsided

in the sample as a whole. Moreover, none of the mothers demonstrated a hand preference in reaching for food or other object. It was difficult to make a reliable observation of the hand use in the infants of these mothers. In another study, we attempted to observe if there was lateralized preference in head turning during the first month for 5 chimpanzee infants who had been separated from their mothers. It proved impossible to carry out—after releasing the head from the middle position it remained there for minutes on end in all 5 infants. In addition, no differences could be felt between hands in terms of the pressure exerted during the grasp response. The number of studies on the development of handedness in nonhuman primates is vanishingly small. The few that there are consist of case studies (e.g. Chorazyna, 1976; Cunningham et al., 1989).

In conclusion, it may be the case that most primate species show a population bias for visually guided reaching with the left arm and those with opposable thumbs a rightsided one for complex manipulations. If this possibility can be more firmly established, then the origins of human handedness may have an evolutionary depth of greater than 4 million years (based on the human–great ape divergence time derived from techniques used in molecular anthropology such as DNA hybridization). Such a depth would suggest handedness preceded the achievement of a persistent upright gait.

SOME (rather) Big Ones

1. Is the neonatal head position a robust phenomenon?

Most probably not. Fullterm newborns subjected to a head midline position for 15 minutes reduced or even lost temporarily a rightward bias in head turning (Turkewitz & Creighton, 1974; see also: Leiderman & Kinsbourne, 1980; Roberts & Smart, 1981). In the ALS, we found that infants of Caribbean origin who were massaged symmetrically on a daily basis by their mothers retained a rightsided bias in head turning, but not for the placing and stepping responses (Hopkins, submitted). Those who were not massaged retained a rightsided preference in all 3 movements—as did a group of Caucasian infants who were also not massaged. We have difficulties in accounting for these findings. The logical follow-up would be an experimental-control group study.

2. When does a lateralized bias for reaching into the contralateral space appear?

The notion that the ability to cross the midline is associated with the maturation of the corpus callosum has been overly stressed. On this view, spontaneous crossing occurs after 1 year. In collaboration with George Butterworth (Univ. Sussex) we found reaching across the midline at 11.3 months for the righthand, then 3 months later in the left. The majority of contralateral reaches terminated in precise finger grips.

3. What other contexts need to be taken into account is studying the development of handedness?

Most research to date has involved studying the lone hander. During

mother-infant interaction the following have been reported: more right hand movements at 2 months associated with positive expressions, more right hand opening at 9 weeks (Fogel & Hannan, 1985) and more right hand 'pointing' when a toy is present (more lefthanded when alone with mother) (Hannan, 1987). Conclusion: different contexts at different ages may evoke different lateralized functions.

4. When does adult like handedness become established?

A long held view is that it is present at about 2 years (Gesell & Ames, 1947; Giesecke, 1936; Hildreth, 1949). More recent studies are less clear: it may be about 3 years (Annett, 1970) or not until after 8 years (Beaumont, 1974; Connolly & Elliott, 1972). Thus, there is little consensus about what constitutes the mature state.

5. Would the study of the development of handedness benefit from a dynamic systems approach?

At the very least, it would force us to identify the appropriate order parameters and to search for age-specific control parameters that might be the agents of change in the order parameters (Hopkins, Beek & Kalverboer, 1993). If there are such things as fluctuating asymmetries in early development, then they may be indicative of transitional periods. Synergetics (Haken, 1977) and catastrophe theory (Gilmore, 1981) provide formal criteria for detecting such phase shifts in order parameters (e.g. critical fluctuations, critical slowing down, sudden jump, bimodality and hysteresis).

REFERENCES

Annett, M. (1970). The growth of manual preference and speed. *British Journal of Psychology*, **61**, 303-321.

Annett, M. (1985). *Left, right, hand and brain: The right shift theory*. Hillsdale, NJ: Erlbaum.

Annett, M. (1978). Throwing loaded and unloaded dice. *Behavioral and Brain Sciences*, **1**, 278-279.

Bakan, P. (1971). Handedness and birth order. *Nature*, 229, 195.

Baldwin, J. M. (1890). The origin of left handedness. *Science*, **16**, 247-248.

Baldwin, J. M. (1894). The origin of right handedness. *Popular Science Monthly*, **44**, 606-615 (cited in Harris, 1983).

Berge, C., Orban-Segebarth, R. & Schmid, P. (1984). Obstetrical interpretation of the Australopithecine pelvic cavity. *Journal of Human Evolution*, **13**, 573-587.

Bradshaw, J. L., Nettleton, N. C., & Spehr, K. (1982). Braille reading and left and right hemispace. *Neuropsychologia*, **20**, 493-500.

Bresard, B. & Bresson, F. (1982). Reaching or manipulation: Left or right? *Behavioral and Brain Sciences*, **10**, 265-266.

Caplan, P. J. & Kinsbourne, M. (1976). Baby drops the rattle: Asymmetry of duration grasp by infants. *Child Development*, **47**, 532-534.

Carlson, D. F., & Harris, L. J. (1985). Development of the infant's hand preference for visually directed reaching: preliminary report of a longitudinal study. *Infant Mental Health*, **6**, 158-174.

Chorazyna, H. (1976). Shifts in laterality in a baby chimpanzee. *Neuropsychologia*, **14**, 381-384.

Chugani, H. T. & Phelps, M. E. (1986). Maturational changes in cerebral function determined by 18

FDG positron emission tomography. *Science*, **231**, 840–843.

Corballis, M. C. & Morgan, M. J. (1978). On the biological basis of human laterality: I. Evidence for a maturational left–right gradient. *Behavioral and Brain Sciences*, **1**, 261–269.

Coryell, J. F. & Michel, G. F. (1978). How supine postural preferences of infants can contribute toward the development of handedness. *Infant Behavior and Development*, **1**, 245–257.

Connolly, K. & Elliott, J. (1972). The evolution and ontogeny of hand function. In N. Blurton-Jones (Ed.), *Ethological studies of child behaviour*. Cambridge: Cambridge University Press, pp. 329–383.

Cunningham, D., Forsythe, C., & Ward, J. P. (1989). A report of behavioral lateralization in an infant orang utan (Pongo pygmaeus). *Primates*, **30**, 249–253.

Beaumont, J. (1974). Handedness and hemisphere function. In S. Dimond & J. Beaumont (Eds.), *Hemisphere function in the human brain*. New York: Wiley, pp. 89–120.

Chi, J. G., Dooling, E. C., & Gilles, F. H. (1977). Gyral development of the human brain. *Annals of Neurology*, **1**, 68–83.

DiFranco, D. Muir, D., & Dodwell, P. (1978). Reaching in very young infants. *Perception*, **7**, 385–392.

Eyre, J. A., & Miller, S. (1992). Assessment of motor pathways. In: Eyre, J. A. (Ed.), *The neurophysiological examination of the newborn infant*. London: Mackeith Press, pp. 124–154.

Fischer, R. B., Meunier, G. F., & White, P. J. (1982). Evidence of laterality in the lowland gorilla. *Perceptual and Motor Skills*, **54**, 1093–1094.

Fogel, A. & Hannan, T. (1985). Manual actions of nine to fifteen week old human infants during face-to-face interaction with their mothers. *Child Development*, **56**, 1271–1279.

Galaburda, A. M., Corsiglia, J., Rosen, G., & Sherman, G. (1987). Planum temporale asymmetry; Reappraisal since Geschwind and Levitsky. *Neuropsychologia*, **25**, 853–868.

Gardner, J., Lewkowicz, D., & Turkewitz, G. (1977). Development of postural asymmetry in premature human infants. *Developmental Psychobiology*, **10**, 19–23.

Gesell, A. & Ames, L. B. (1947). The development of handedness. *Journal of Genetic Psychology*, **70**, 155–175.

Giesecke, M. (1936). The genesis of hand preference. *Monograph of the Society for Research in Child Development*, **1** (Serial No. 5), 1–102.

Goodwin, R., & Michel, G. F. (1981). Head orientation position during birth and in infant neonatal period, and hand preference at nineteen weeks. *Child Development*, **52**, 819–826.

Hannan, T. (1987). A cross-sequential assessment of the occurrences of pointing in 3- to 12-month-old human infants. *Infant Behavior and Development*, **10**, 11–22.

Harris, L. J. (1983). Laterality of function in the infant: Historical and contemporary trends in theory and research. In G. Young et al. (Eds.), *Manual specialization and the developing brain*. New York: Academic Press, pp. 177–247.

Hawn, P. R. & Harris, L. J. (1983). Hand differences in grasp duration and reaching in two- and five-month-old infants. In G. Young et al. (Eds.), *Manual specialization and the developing brain*. New York: Academic Press, pp. 331–348.

Hepper, P. G., Shahidullah, S. & White, R. (1991). Handedness in the human fetus. *Neuropsychologia*, **29**, 1107–1111.

Hildreth, G. (1949). The development and training of hand dominance: I. II. III. *Journal of Genetic Psychology*, **75**, 197–275.

Hopkins, B., Lems, W., Janssen, B., & Butterworth, G. (1987). Postural and motor asymmetries in newly borns. *Human Neurobiology*, **6**, 153–156.

Hopkins, B., Lems, Y. L., van Wulfften Palthe, T., Hoeksma, J., Kardaun, O., & Butterworth, G. (1990). Development of head position preference during early infancy: a longitudinal study in the daily life situation. *Developmental Psychobiology*, **23**, 39–53.

Hopkins, B., Beek, P. J., & Kalverboer, A. F. (1993). Theoretical issues in the longitudinal study of motor development. In: Kalverboer, A. F., Hopkins, B., & Geuze, R. (Eds.), *Motor development in early and later childhood: Longitudinal approaches*. Cambridge: Cambridge University Press, pp. 343–371.

Hopkins, W. D., Washburn, D. A., & Rumbaugh, D. M. (1989). Note on hand use in the manipulation of joy sticks by rhesus monkeys (Macaca mulatta) and chimpanzees (Pan trolodytes). *Journal of Comparative Psychology*, **103**, 91–94.

Humphrey, T. (1964). Some correlations between the appearance of human fetal reflexes and the development of the nervous system. *Progress in Brain Research*, **4**, 93–135.

Konishi, Y., Kuriyama, M., Mikawa, H., & Suzuki, J. (1987). Effect of body position on later postural and functional lateralities of preterm infants. *Developmental Medicine and Child Neurology*, **29**, 751–757.

Kooistra, C. A. & Heilman, K. M. (1988). Motor dominance and lateral asymmetry of the globus pallidus. *Neurology*, **38**, 388–390.

Kuypers, H. G. J. M. (1985). The anatomical and functional organization of the motor system. In M. Swash & C. Kennard (Eds.), *Scientific basis of clinical neurology*. Edinburgh: Churchill Livingstone, pp. 3–18.

Levy, J. & Nagylaki, T. (1972). A model for the genetics of handedness. *Genetics*, **72**, 117–128.

Liederman, J. & Kinsbourne, M. (1980). Rightward motor bias in newborns depends upon parental right handedness. *Neuropsychologia*, **18**, 579–584.

Manning, J. T., & Chamberlain, A. T. (1990). The left side cradling preference in great apes. *Animal Behaviour*, **39**, 1224–1226.

McDonnell, P. M. (1979). Patterns of eye hand coordination in the first year of life. *Canadian Journal of Psychology*, **33**, 253–267.

MacNeilage, P. F., Studdert Kennedy, M. G., & Lindblom, B. (1987). Primate handedness reconsidered. *Behavioral and Brain Sciences*, **10**, 247–303.

Michel, G. F. (1981). Right handedness: A consequence of infant supine head orientation? *Science*, **212**, 685–687.

Michel, G. F. & Goodwin, R. (1979). Intrauterine birth position predicts newborn head position preferences. *Infant Behavior and Development*, **2**, 29–38.

Michel, G. F. & Harkins, D. A. (1986). Postural and lateral asymmetries in the ontogeny of handedness during infancy. *Developmental Psychobiology*, **19**, 247–258.

Michel, G. F., Ovrut, M. R., & Harkins, D. A. (1985). Hand use preference for reaching and object manipulation in 6 through 13 month old infants. *Genetic, Social, and General Psychology Monographs*, **111**, 407–428.

Mittwoch, U. (1978). Changes in the direction of the lateral growth gradient in human development – left to right and right to left. *Behavioral and Brain Sciences*, **2**, 306–307.

Nijhuis, J. G., Prechtl, H. F. R., Martin, C. B., & Bots, R. S. G. R. (1982). Are there behavioural states in the human fetus? *Early Human Development*, **6**, 177–195.

Petrie, B. F. & Peters, M. (1981). Handedness: Left right differences in intensity of response and duration of rattle holding in infants. *Infant Behavior and Development*, **3**, 215–221.

Pipe, M. E. (1990). Mental retardation and left handedness: Evidence and theories. In: Coren, S. (Ed.), *Lefthandedness: Behavioral implications and anomalies*. Amsterdam: North Holland, pp. 293–318.

Previc, F. H. (1991). A general theory concerning the prenatal origins of cerebral lateralization in humans. *Psychological Review*, **98**, 299–334.

Ramsay, D. (1980a). Onset of unimanual handedness in infants. *Infant Behavior and Development*, **3**, 377–385.

Ramsay, D. (1980b). Beginnings of bimanual handedness and speech in infants. *Infant Behavior and*

Development, **3**, 67–77.

Roberts, A. M. & Smart, J. L. (1981). An investigation of handedness and headedness in newborn babies. *Behaviour and Brain Research*, **2**, 275–276.

Satz, P. (1972). Pathological handedness: An explanatory model. *Cortex*, **8**, 121–135.

Schwartze, H. & Schwartze, P. (1977) Physiologie des foetal , neugeborenen- und kindesalters. Berlin: Akademie-Verlag.

Seth, G. (1973). Eye-hand co-ordination and "handedness": A developmental study of visuomotor behaviour in infancy. *British Journal of Educational Psychology*, **43**, 35–49.

Tobias, P. V. (1981). The emergence of man in Africa and beyond. *Philosophical Transactions of the Royal Society of London*, B., **292**, 43–56.

Toth, N. (1985). Archaeological evidence for preferential right handedness in the lower and middle Pleistocene and its possible implications. *Journal of Human Evolution*, **14**, 607–614.

Touwen, B. C. L. (1976). *Neurological development in infancy*. London: Heinemann.

Touwen, B. C. L. (1978). Variability and stereotypy in normal and deviant development. In J. Apley (Ed.) *Care of the handicapped child*. London: Heinemann, pp. 99–110.

Turkewitz, G. & Creighton, S. (1974). Changes in lateral differentiation of head posture in the human neonate. *Developmental Psychobiology*, **8**, 85–89.

Visser, G. H. A., Zeelenberg, H. J., de Vries, J. I. P., & Dawes, G. S. (1983). External physical stimulation of the human fetus during episodes of low heart rate variation. *American Journal of Obstetrics and Gynecology*, **145**, 579–584.

von Hofsten, C. (1982). Eye-hand coordination in the newborn. *Developmental Psychology*, **18**, 450–461.

Yakovlev, P. I. & Rakic, P. (1966). Patterns of decussation of bulbar pyramids and distribution of pyramidal tracts on two sides of the spinal cord. *Transactions of the American Neurological Association*, **91**, 336–367.

Young, G. (1977). Manual specialization in infancy: Implications for lateralization of brain functions. In S. J. Segalowitz & F. A. Gruber (Eds.) *Language development and neurological theory*. New York: Academic Press, pp. 289–311.

Young, G. (1990). The development of hemispheric and manual specialization. In: Hammond, G. R. (Ed.). *Cerebral control of speech and limb movements*. Amsterdam: North Holland, pp. 79–139.

Young, G., Segalowitz, S., Misek, P., Alp, I., & Boulet, R. (1983). Is early reaching left handed? Review of manual specialization research. In G. Young et al. (Eds.) *Manual specialization and the developing brain*. New York: Academic Press, pp. 13–32.

Yu Yan, M., Cun-Ren, F., & Over, M. (1983). Lateral symmetry in duration of grasp by infants. *Australian Journal of Psychology*, **35**, 81–84.

DYNAMICS OF SELF ORGANIZATION IN HUMAN LOCOMOTION

R. E. A. van Emmerik and
R. C. Wagenaar
Free University Amsterdam Hospital

Within the framework of the dynamical systems theory of movement coordination and control we provide tools and methods to study coordination changes and stability characteristics in human locomotion. The first part of the paper offers a tutorial on dynamical systems principles, in particular what the central tenets are of a law based approach to movement coordination. This law based approach emphasizes the self organizing principles that underly the formation of new movement patterns and the unity in organizing strategies across scales of observation (Kugler & Turvey, 1987). Central to the formation of new patterns is the thermodynamic theory of dissipative structures as developed by Prigogine (1980). We then turn to a description of mechanical pendular properties of the rhythmic oscillations of the limbs and assess their different stability characteristics of mechanical and dissipative processes. Different approaches (e.g., dissipative structures, synergetics theory and dynamical models) that directly relate to the formation of new movement patterns are elaborated upon. The second part of the paper provides empirical data from our own research, using dynamical systems tools and principles in studying coordination changes in healthy and pathological gait. Finally, we discuss some of the implications of this dynamical approach for the study of developmental changes in locomotory patterns.

key words gait transitions, nonlinear dynamics, relative phase dynamics, control parameters, pattern stability

Introduction

How does an infant discover a new locomotory pattern? How does it stabilize this newly acquired pattern? And how do transitions from standing to walking or between walking and running emerge? In this paper we would like to address these kinds of questions using principles and methods that emphasize physical descriptions of locomotion that closely approximate a pendular, clocking (limit cycle) mode of organization (Kugler & Turvey, 1987). The approach advocated by Kugler & Turvey (1987) emphasizes transformation and conservation mechanisms of energy processes as a possible source of order. These transformation and conservation processes can be observed at different frames of reference, namely the macro-mechanical and micro-thermodynamical. In the following sections it will be shown that the emergence of new patterns result from the interplay between mechanical and thermodynamical (dis-

sipative) processes. These descriptions and formalisms are presented within the framework of the 'dynamical systems approach' to movement coordination and control, which is based on recent developments in nonlinear dynamics (e.g., Thompson & Stewart, 1986) and ecological psychology (e.g., Gibson, 1979). General principles and methods of this theory will be laid out, and we will illustrate these with data from our own work that is concerned with the evaluation and treatment of movement disorders in neurologically disabled individuals. Finally, we will discuss some of the implications of this approach for the study of coordination changes in motor development.

A Law based Approach to Movement Coordination

One of the outstanding questions in the area of motor control is how the multiple degrees of freedom in the human body are coordinated and controlled in a coherent fashion. Bernstein (1967) was one of the first who recognized the complexity of the movement control system and systematically investigated how in the course of learning the available degrees of freedom are utilized, and, eventually mastered. Whether at a biochemical, muscular, or biomechanical level, biological systems encompass numbers of degrees of freedom that widely surpass those of artificial (engineering) systems. Also, there is no straightforward, unambiguous relation between afferent signals to muscles and corresponding movements. This implies that individual muscles and their innervational states do not have fixed movement consequences, and that movement outcomes are dependent upon contextual contingencies ('context conditioned variability', Turvey, 1990). This context conditioned variability is also visible in current mass spring models of motor control (e.g., Feldman, 1986). In Feldman's equilibrium point hypothesis, states of the motor system are described in equilibrium states which are dynamically assembled from the interaction of centrally regulated nonlinear thresholds on the motor neuron pool and the active loading of the musculo skeletal system.

The dynamical systems approach provides a law based account of how interactions between systems develop, stabilize, and change. Natural laws couple physical symmetries, which are defined by kinematic variables. Natural laws explain the stability and reproducibility of events and have only qualitative invariance, in that they identify qualitative geometric (or topological) relations which remain invariant under certain system transformations. Typically, natural laws are defined over the dimensions of mass, length, and time (see Kugler & Turvery, 1987). In traditional hierarchies in biological explanation, biological systems are considered to be holistic, whereas physical explanations are unit explanations and reductionist. The reductionism in a law based program towards biological systems is of a fundamentally different kind because it is searching for universal organizing strategies applicable across various disciplines of the natural sciences or scales of observation (Haken, 1977; Kugler & Turvey, 1987; Soodak & Iberall, 1978).

Despite the ubiquity of cross scale interactions, the physical and social sciences have long been preoccupied with same scale interactions (Kugler & Shaw, 1990). The laws that have been proposed operate essentially at the same scale, refer to system dynamics that are reversible, and assume that first principles (such as the first and second laws of thermodynamics) are weakly and linearly coupled. Under this assump-

tion, high dimensionality or variability in the movement system is viewed as a curse, to be avoided and eliminated. In the dynamical approach this variability and dimensionality is to be exploited, in that symmetry preserving and symmetry breaking strategies are considered as consequences of nonlinear couplings of these first principles that operate across scales (physical, biological, psychological).

Thermodynamic principles: Dissipative structures

Traditional theories of motor behavior (e.g., Adams, 1971; Schmidt, 1975) contemplate the moving organism as a closed system in which order, stability, uniformity, and equilibrium are emphasized. Linear relations in which small (large) inputs give rise to small (large) outputs dominate in these types of systems. Order, stability, and equilibrium in closed systems are fundamental aspects of classical mechanics, while in thermodynamics new models were developed in which energy, matter, and information are exchanged with the environment. Thermodynamics deals with the transactions of various forms of energy in all its possible forms, and is described by phenomena such as pressure, concentration, temperature, etc. Fluctuations and stochastic processes are essential, and in addition to conservative mechanical forces thermal flows exist which compete with the conservative forces, thereby increasing the order of the system.

In this view, macroscopic processes contain microscopic processes, and fluctuations at the micro level can fundamentally change the existing order at the macroscopic level. A system can disintegrate into chaos or jump to a higher level of organization. This higher level of organization is called a 'dissipative structure' (Prigogine, 1980). Dissipative structures require more energy to sustain their action, compared to the more simple structures from which they unfold. Prigogine (1980) emphasizes disorder instead of order, instability instead of stability, disequilibrium instead of equilibrium, and nonlinear relations in which small inputs can trigger disproportionately large outputs. These nonlinear relations are considered common whereas linear relations are considered rare.

The theoretical perspective on movement advocated by Kugler and Turvey is called the natural physical perspective of biological organization because it is grounded in the dynamic principles of physical theory (the physical theory as outlined by Prigogine) and ecological realism (Gibson, 1979). Essential to the natural physical perspective is the dissipative structure concept as advocated by Prigogine. In far from equilibrium conditions individual degrees of freedom (atoms, muscles, organisms) can change their behavior from unstable, chaotic, and random to a highly structured organization. In the latter stage all the degrees of freedom change or interact simultaneously, creating a sort of chemical or biological clock. The highly synchronized behavior and entrainment is an example of a self organization process. The natural physical perspective provides an understanding of how macroscopic patterns (whether at a molecular, biological, or social system level) can be temporarily assembled, sustained, and dissolved with no a priori set of logical constraints. What emerges is a theory of self organizing systems, addressing directly the problem of morphogenesis in which circular interactions between low energy kinematic flow fields and high energy force fields are fundamental (e.g., see Kugler, 1986 for an application to motor development).

This intricate unity of action and perception is the hallmark of Gibson's (1979) theory of perception.

Central aspects of the theory of self organizing systems are principles related to geometry and physics. The geometric principles are intrinsically related to the process of morphogenesis. Morphogenesis is defined by Waddington (1970) as the coming into being of characteristic or specific form in living organisms. A geometric or morphogenetic analysis focuses on intrinsic symmetries (also called 'similitudes'), and how these symmetries are sustained under some scale changes (structurally stable) and annihilated under others (structurally unstable). A physical analysis focuses on the identification of these symmetry-breaking mechanisms and on *how* qualitative changes ('bifurcations') occur (e.g., Abraham & Shaw, 1984). Nonequilibrium nonlinear thermodynamics is the area describing these symmetry-breaking mechanisms.

Any spontaneous process results in an increase in the disorder of the system and its surrounding. This is essentially what is stated in the second law of thermodynamics. Closely related to the second law is the entropy concept, which is defined as a state or condition of matter and energy identified with randomness or disorder. A corollary of the second law is that physical and chemical processes evolve in the direction of maximal entropy, i.e. maximal disorder. When the entropy of a system remains constant, the process is called reversible. This could occur theoretically in an isolated system where no change of energy and matter with the surrounding is possible. In contrast to reversible processes, the entropy production is always greater than zero in irreversible processes. These irreversible processes are unidirectional, and are the hallmark of open systems. In an open system energy and matter can be exchanged with the surrounding. In isolated systems the entropy production increases until thermodynamic equilibrium and the spontaneous formation of new states of structures is not possible (Nicolis & Prigogine, 1977; Prigogine, 1980). For an open system, however, the competition between entropy flow in the system and the exchange with the environment permits the system to adopt new structures and new forms. Open systems are in a steady state, whereas isolated systems are in true equilibrium (von Bertalanffy, 1968).

In conditions *near* equilibrium thermodynamic forces are weak and the response to small perturbations from the steady state results in a damping behavior, linearly proportional to the magnitude of the perturbation. This response to perturbations is similar to the behavior in the equilibrium condition. As a consequence, the development of a new and more complex order is impossible in this linear range of the equilibrium condition (Prigogine, 1980). When the perturbations acting on the system exceed the linear range, the independence from fluctuations and the stationary state of the system disappears. Fluxes now become more complex nonlinear functions and under certain conditions far from equilibrium fluctuations may be amplified bringing the system to a new order.

The term 'dissipative structure' emphasizes the close association between structure and order on one side, and dissipation or waste on the other (Prigogine & Stengers, 1984). In classical linear thermodynamics heat (or the incoherent transfer of energy) was considered a form of waste, but in nonlinear, nonequilibrium ther-

modynamics this transfer or energy dissipation becomes a source of order. Far from equilibrium a marginal state of stability is created in which a sudden transition moves the system towards instability, leading in turn to fluctuations and eventually to a new order. Symmetry breaking instabilities can result from scaling up or down a single parameter into the nonlinear range. New stabilities may develop beyond a certain critical scale value. The critical scale value can be expressed in a dimensionless number (also called 'π number'), which is intrinsic to the system and expresses the deviation from the internal equilibrium state.

It must be emphasized that dissipative structures are not only characterized by their ability to self organize, but also by their ability to resist changing initial and boundary conditions that describe the relation of the system with its environment. Dissipative structures are autonomous in that they are relatively unaffected by perturbations to initial and boundary conditions. Small deviations do not change the behavioral pattern of these structures, a principle known as the equifinality principle (von Bertalanffy, 1968), which is an important aspect of dynamic mass spring models in motor control.

Mechanical aspects : Scaling relations and pendulum models

A law based account of the coordination and control of movement searches for a description of the rhythmic movements of the limbs in higher and lower animals in terms of the fundamental relations of mass, length, and time. Using the wrist pendulum system as a model for the oscillatory properties of the limbs during locomotion, Kugler and Turvey (1987) derived a fundamental scaling law that captures the relation between periodic time, mass and length :

$$t_c = a_i (M^{1/8} L^{1/2})^{c_i} \quad \cdots\cdots (1)$$

where M is the mass and L is the length of the limb or oscillator. Individual subject characteristics (e.g., anthropometric or internal control aspects) are viewed as nonuniform coordinate spaces in which the invariant law is embedded. These are evident in different scalar and vector potentials and indexed by a_i and c_i, respectively.

Kugler and Turvey (1987) analyzed the different gaits in a variety of animals from data by Pennycuick (1975). Regression analyses in double log coordinates revealed that for the walk, trot, and canter periodic times scaled, apporoximately, to mass raised to the 1/8 power (.16 for walking, .13 for trotting, and .12 for cantering) and to length raised to the 1/2 power (.49 for walking, .48 for trotting, and .44 for cantering). As animals increase or decrease locomotory speed, there is an increase in the irreversible flow of chemical energy into mechanical energy. This transformation is a scalar one, however, as the above relations between periodic time, mass, and length remain invariant.

What does distinguish the different coordinative modes is that these regression lines do not overlap, i.e., not all periodicities are accessible for each gait. Kugler & Turvey suggest that it is the constant of acceleration due to gravity that governs the quantization of the different gait spectra :

$$t = 2\pi\sqrt{(L/ng)} \quad \cdots\cdots (2)$$

For an ordinary physical pendulum, n = 1. For walking, trotting, and cantering, n was

found to be 1.95, 6.96, and 9.73, respectively. This suggests that different gaits are organized around integer multiples of the gravitational field intensity, and that animals organize their locomotory patterns on the basis of the reactive forces that emerge in the gravitational field.

Stability properties of mechanical and dissipative systemes

The mechanical, conservative laws describe physical conditions in which reversible energy transformation takes place (between potential and kinetic) without degradation or dissipation. This system is inherently unstable with respect to external perturbations. A perturbation leads to a change in the momentum and observed behavior of the system. This is illustrated in the 'phase plane' configuration in Figure **1a**, in which the variable on the abscissa identifies the position variable (X) and the variable on the ordinate the velocity (V). A perturbation (small and large) applied to a conservative system will cause the system to adopt a new state (different orbit in the phase plane).

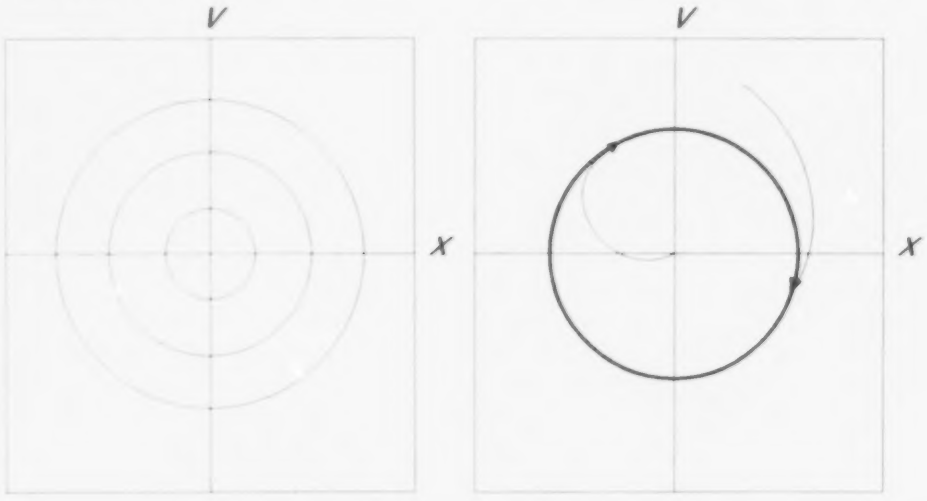


FIGURE 1 Phase plane plots for a conservative (a) and nonconservative (limit cycle) system (b). The position variable is on the ordinate (X) and the velocity variable is on the abscissa (V).

In nonconservative processes on the other hand, the work cycle is formed as a result of irreversible transformations in the energy distributions from a macro to a micro frame of reference. This transfer takes place from a higher potential source to a lower potential sink. Qualitatively, the behavior of this work cycle is that of a limit cycle: a closed orbit in the phase plane (see Figure **1b**). Characteristic of the limit cycle is it's stability to perturbations and return to the same stable orbit, following different kinds of perturbations. Only very strong perturbations could possibly lead to another mode of organization. The limit cycle is therefore proposed as the basic unit of an autonomous system (Kugler et al., 1980; 1982).

The contribution of conservative (mechanical) and nonconservative (dissipative) elements is identified by a dimensionless number called the Q factor. The number is obtained by dividing the average energy carried by mechanical processes (Em) by the average energy carried by thermodynamical processes (Et):

$$Q = Em / Et \quad \cdots\cdots(3)$$

A system with a high Q factor stores a lot of the energy in the macroscopic force structure (the oscillations of the limbs, for example). Very little energy flows from macro to micro levels and there is no dissipation of energy. A low Q factor is a system that stores very little energy at the macro mechanical level but absorbs most of the energy at a more micro level through dissipation. These two systems have very different stability features: high Q factors lead to unstable systems, low Q factors to stable systems.

The Emergence of New Movement Forms: Phase Transitions

The Interplay between mechanical and dissipative processes

A consequence of the framework presented above is that new forms can only arise from the interplay between reversible and irreversible transformations of energy. A reversible transformation occurs within a single frame of reference, for example the macroscopic mechanical. Here we only encounter transformation in the from of the energy (potential and kinetic). Irreversible processes identify the flow of energy of one frame of reference (macroscopic mechanical) to another (microscopic thermodyamical), in which constraints are broken (second law of thermodynamics) and assembled (see Kugler & Turvey, 1987 for a full discussion). This assembly arises from the emergence of long range correlations at the micro level.

An illustrative example of these different energy flows and the interchange between conservative and nonconservative processes is provided by the dynamics of a falling leaf (Kugler & Turvey, 1987; Kugler et al., 1990). When dropped from a sufficient height; a leaf might exhibit three qualitatively different modes of organization, namly: a translation, a vibration, and a spinning mode. The first is the translational mode, in which the leaf is falling down in a more or less straight path. More and more energy is absorbed while falling down (the leaf loses potential energy and gains kinetic energy) until a critical point is reached where this mode is no longer stable. At the critical point (height) the leaf self-organizes into a new vibration mode. This new mode can consume or dissipate the increasing kinetic energy that is being pumped into the system and stabilizes the dynamics. If the leaf keeps falling this mode will eventually become unstable as well, and a new mode that can contain more of the energy spontaneously emerges. This third mode is the spinning mode. Kugler and colleagues use this example to demonstrate that increasing the amount of energy flow into the system can lead to the emergence of new movement forms through a process of self-organization. In other words, new movement forms emerge through energy-exchanges of the system with its environment and are not prescribed a priori in the structural elements.

In biological organisms a prereguisite for the emergence of these new forms is the coupling between high energy action fields that arise from the internal degress of

freedom of the organism (micro states) and the low energy perceptual (flow) fields. Due to their on board energy reservoirs and ability to produce suitably large forces, biological organisms can time delay energy transactions and are not guided solely by the reactive forces that arise from the organism's presence in the environment (Kugler & Turvey, 1987). These nonmechanical interactions have been termed 'perceptual' and emerge through the availability of low energy fields (e.g., sound, light), which are lawfully structured by the high energy matter fields (layout of surfaces). Flow morphologies that can be defined on these low energy fileds are potential sources of information about the dynamics that give rise to them.

New movement forms or coordinative structures do not emerge on the basis of 'hard molded', high energy force interactions but arise through 'soft molded', low energy flow morphologies present in the neural fields. New structures develop through a circular causality between the low energy flow fields (perceptual aspects) and the high energy action fields.

In the following sections we will elaborate on models in which this formation of coordinative structures is not construed physically but mathematically.

The Synergetics Approach

Relevant to identifying the nature of coordination changes is the distinction in synergetics (Haken, 1977; Schöner & Kelso, 1988) between order and control parameters. Order parameters identify low dimensional qualitative states ('macro states') of the system dynamics, in which changes between modes can be induced by manipulating an aspecific control parameter, such as frequency or velocity. Phase relations between body segments are considered order parameters because of their fundamental reflection of cooperativity between components in the system ('micro states'). Relative phase between component oscillators (fins, hands, legs, etc.) can identify different qualitative states of the system dynamics (e.g., in phase and out of phase) on which basis changes in coordination patterns can be evaluated.

Synergetics offers tools to study the nature of these phase transitions. Discontinuous transitions are characterized by abrupt jumps between different coordinative modes; these abrupt jumps can occur for very small changes in the control parameter (nonlinearity). Continuous phase transitions are more or less smooth and can occur over a larger interval of control parameter values. Critical in distinguishing these two types of transitions is the stability of the order parameter: only in abrupt transitions instability occurs before the transition point. This instability can be measured by means of fluctuations (standard deviation) in relative phase or the relaxation time after a transient perturbation. The observation of critical fluctuations and corresponding loss of stability in the order parameter is dependent upon several time scales relations: T_{obs} the time over which the control parameter is changed or the system is measured; T_{rel} the local relaxation time after a perturbation; and T_{equ} the global relaxation time which is a probabilistic entity and indicates the time it would take for the system to visit all its possible states without a change in control parameter. If $T_{rel} \ll T_{obs} \ll T_{equ}$ then the different qualitative states are considered stationary stable states and transitions involve a loss of stability and increased fluctuations. If $T_{rel} \ll T_{equ} \ll$

T_{obs} then the system is not in a stationary state and no loss of stability is predicted. Control parameter changes can also lead to 'hysteresis': where and when abrupt jumps in coordination patterns occur is dependent on the way the control parameter was changed. Parametric changes in which the control parameter increases and decreases can lead to different coordinative modes at the *same* control parameter value.

Schöner et al. (1990) proposed a model of quadrupedal gaits and gait transitions based on the synergetics approach. They defined symmetry as the invariance of the phase vector representing the phases of the component oscillators. Patterns like the gallop, trot, and pace are symmetrical with respect to spatial symmetry operations of left right limb and front hind girdle exchanges, as well as temporal inversion, and can be considered stable independent attractors of the system dynamics. Attractors identify preferred modes of organization, and the limit cycle in the phase plane (see Figure 1b) is an example of an attractor. A pattern like the walk, however, is multistable under these symmetry requirements: two alternative modes, the 'straight' and the 'reverse' walk, can exist as dynamically equivalent degeneracies (Schöner et al., 1990), which can only become stable independent states when symmetry breaking occurs through lowering the symmetry of the dynamics. Under certain symmetry conditions and parametric changes both abrupt and continuous changes in the coordination between homologous and nonhomologous limbs are predicted. This in contrast to observations from bimanual hand and finger movements where abrupt changes have been observed (Haken et al., 1985; Kelso et al., 1986). These different transition patterns can be related to the number of components and asymmetries in the system that reflect different stabilities in the relative phase between the component oscillators, which in turn are reflections of the overall stability and adaptability of the movement control system.

Dynamical models: The importance of control parameters

Glass and Mackey (1987) recognize the human body as a complex spatio temporal organization, in which different diseases emerge when the normal organization breaks down and is replaced by some abnormal dynamic. This so called 'dynamical diseases' approach investigates the nature of abnormal biological rhythms on the basis of nonlinear mathematical models, in which control parameters are essential in inducing a pattern change. Although it is evident that pathologies are related to structural abnormalities as well as system control processes, the latter have received scant attention in the medical literature.

Glass and Mackey distinguish three types of qualitative changes in dynamical diseases, i.e.: 1) the appearance of regular oscillations in a biological control system that normally does not show oscillatory behavior; 2) the appearance of new periodicities in a process that is already periodic; and 3) the disappearance of rhythmic processes. These qualitative changes can be observed in movement coordination present in standing and walking: the initiation of gait involves starting a rhythmic process, coordination changes during walking often involve introducing new periodicities, and stopping requires the disappearance of the on going rhythm.

Akamatsu et al. (1986) have recently developed a dynamic model of the oscil-

latory properties of the length tension relations in human muscle based on a population dynamics model or logistic difference equation by May (1977):

$$x_{n+1} = \alpha x_n (1 - x_n) \qquad 0 \leq \alpha \leq 4,$$

where x_n is the generated muscle length or joint angle at moment n, x_{n+1} the length or angle at moment n + 1, and α is a control parameter, for example indicating the degree of muscle activation. This model is able to generate very different movement dynamics as a function of scaling the control parameter α. When α has low values the model predicts that from moment to moment there are no systematic changes in muscle length or joint angle. In dynamical terms, this state of organization is called a 'fixed point attractor'. When α is increased the steady state remains until α reaches a critical value, at which point the muscle length or joint angle starts to oscillate between two fixed values from one moment to the next, and the dynamic of the 'limit cycle' or 'periodic attractor' emerges (see Figure 1b). If parameter α increased even more then a period doubling occurs from a period 2 to a period 4 to a period 8 oscillation, and so on. Eventually, when α reaches a critical value the oscillations are not periodic, but almost periodic or 'quasiperiodic'. At even higher values of α there is a change to 'chaotic' dynamics in which the movement becomes more and more unpredictable. These qualitative changes from steady state to periodic to quasiperiodic to chaotic behavior are also referred to as 'bifurcations'. An example of a bifurcation diagram is presented in Figure 2. The control parameter α is plotted on the abscissa, and the variations in muscle length or joint angle on the ordinate.

This dynamic model demonstrates that a simple mathematical model for muscle or population dynamics can generate complex types of oscillatory behavior, and that bifurcations between these different dynamics occur for very specific values of a single control parameter. In the dynamical diseases approach the existence of multiple rhythms or periodicities does not have to imply that the underlying organization of the movement control variables has to be complex, i.e. that all these periodicities have to be represented in the control system. On the contrary, manipulation of only one control parameter can generate different types of dynamics, ranging from no observable periodicity to simple and complex oscillations.

Winfree (1980; 1987), one of the pioneers in research on biological rhythms, described and modelled phase resetting dynamics in a wide variety of biological organisms. Mosquitos, for example, show a circadian activity pattern of approximately 23 hours; their humming increases at sunset and sunrise. When a group of these mosquitos is kept in a dark cage they exhibit their regular 23 hour cycle. After applying a strong light pulse for about 7.5 minutes, however, there is a shift in the phase or rhythm of activity; this shift is either a deceleration or an acceleration with respect to the old phase or rhythm. In the plot of old phase versus new phase these shifts can be seen as oscillations around the diagonal (representing no phase shift, where new phase equals old phase). This resetting of rhythmic behavior in which there is only a slight shift with respect to the old phase is called 'type 1' or uneven phase resetting. A different type of phase resetting occurs when a strong stimulus with a duration of 2 hours instead of 7.5 minutes resets the activity patterns of the mosquitos to one complete period. This type of phase resetting is called 'type 0' or even resetting and the changes

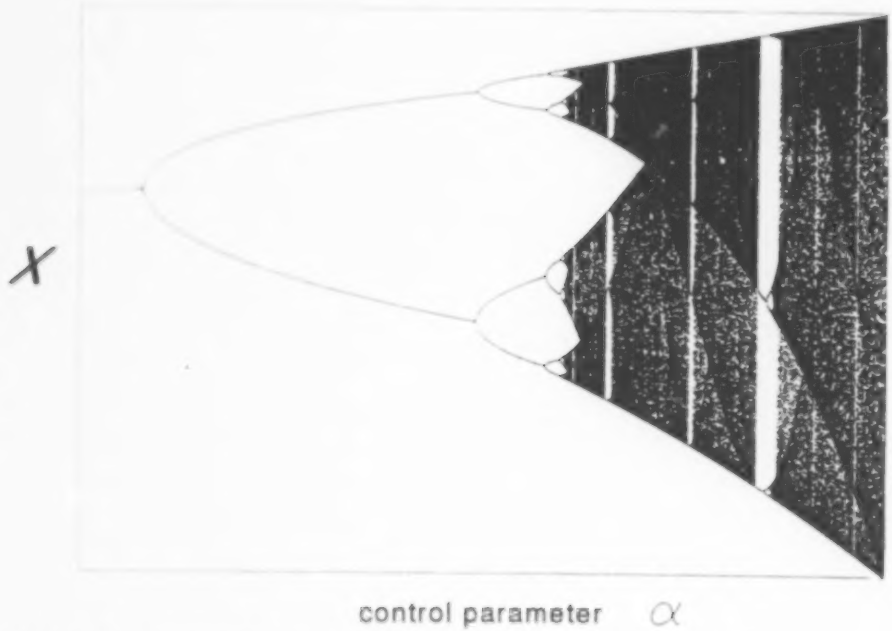


FIGURE 2 Bifurcation diagram with control parameter α on the abscissa and the variation in muscle lenght or joint angle on the ordinate. Bifurcations take place at specific values of the control parameter. At the first bifurcation point the dynamic changes from a steady state (no oscillations) to a stable limit cycle (period two oscillation) in which two different joint angle configurations are adopted during a cycle. At higher values of α a bifurcation to a period 4 oscillation emerges, and at even higher values a bifurcation to a period 8, etc.

in new phase take place around a horizontal line.

Winfree has further developed these different types of resetting in so called 'time crystals', that represent the geometric properties of old phase versus new phase as a function of changes in a control parameter, such as the duration of the light pulse in the example above. Gradually increasing the pulse duration will change the resetting curve from uneven to even (from type 1 to type 0). The point where this transition occurs is called the 'singularity point'. If a stimulus of a particular duration and administered at a certain moment in the on going pattern brings the system in this singularity point, then the oscillation is extinguished or can become chaotic.

These models are important in different areas of medicine, like sudden heart death in which no known structural abnormalities could be detected (Goldberger et al., 1990). They demonstrate that pathologies can arise from specific constraints on the dynamics. Winfree's time crystal models also show that different types of phase resetting do not have to be attributed to different 'clock' mechanisms in biological systems; they simply arise as a result of the same underlying dynamic when system control parameters are scaled.

We now turn to discussion of the application of dynamical systems' principles and the relevance of control parameter manipulations in the investigation of gait

changes and stability of gait in normal and pathological human walking.

Empirical Data: Transitions and Stability in Locomotion

In bipedal locomotion coordination patterns like the walk and run have been identified as qualitatively different modes. It is often assumed that within these modes only linear scaling can occur: the studies were focused on changes in spatio-temporal characteristics in the step patterns of the lower extremities did find systematic linear increases in stride frequency and stride length when walking velocity was increased (e.g., Andriacchi et al., 1977; Larsson et al., 1980). A number of studies, however, suggest a transition in frequency and phase relations in bipedal walking within the velocity range 0.75-1.0 m/s (e.g., Craik et al., 1976; van Emmerik and Wagenaar, 1992; Wagenaar & Beek, 1992; Wagenaar & van Emmerik, in press).

This section focuses on the identification of different coordinative modes and the nature of transitions between these modes in human walking using tools from the dynamical systems approach. The question is whether the changes described in the model of Schöner et al. (1990) on quadrupedal locomotion also occur in the human bipedal walking mode. Coordination changes in relative phase between thoracic and pelvic rotations, as well as between arm and leg movements, were examined while movement speed and stride frequency were manipulated as control parameters. The nature of the transition and the stability of the pattern can be characterized by the variability in the order parameter relative phase: abrupt transitions between coordinative modes show large increases in variability of relative phase before and at the transition point, whereas more gradual transitions do not show these increases in variability.

Transitions in the kinematics of the trunk

Changes in coordination patterns as a function of walking velocity have also been observed for motions of the trunk and head during locomotion (e.g., Cappozzo et al., 1981). Head, thorax and pelvis move in coordinated fashion in order to minimize mechanical energy variations during the walking cycle. Coordination problems in trunk rotations have also been identified as determinants of movement pathologies in stroke patients (Wagenaar & Beek, 1992) and Parkinsonian patients (Murray, 1978; van Emmerik et al., 1993).

Wagenaar and Beek (1992) observed systematic changes in the phase relation between pelvic and thoracic rotations by continuously scaling walking velocity. This phase relation changes from a more in phase pattern (about 25 degrees) at low speeds to a more out of phase pattern (about 120 degrees) at higher walking speeds. Dimensionless analysis revealed changes in the coordination of trunk and pelvis rotations: an optimal coupling in the coordination of the trunk and a sudden increase in transversal pelvic rotation emerged in the velocity range 0.75-1.0 m/s.

Our present data elaborate on these findings and investigated the *nature* of these coordination changes and the *stability* of the patterns. In Figure 3 is presented the changes in relative phase between pelvis and thorax as a function of walking velocity for a healthy subject and a patient with Parkinson's disease. In the healthy subject (bold solid line) relative phase changes from a more in phase relation at lower veloc-

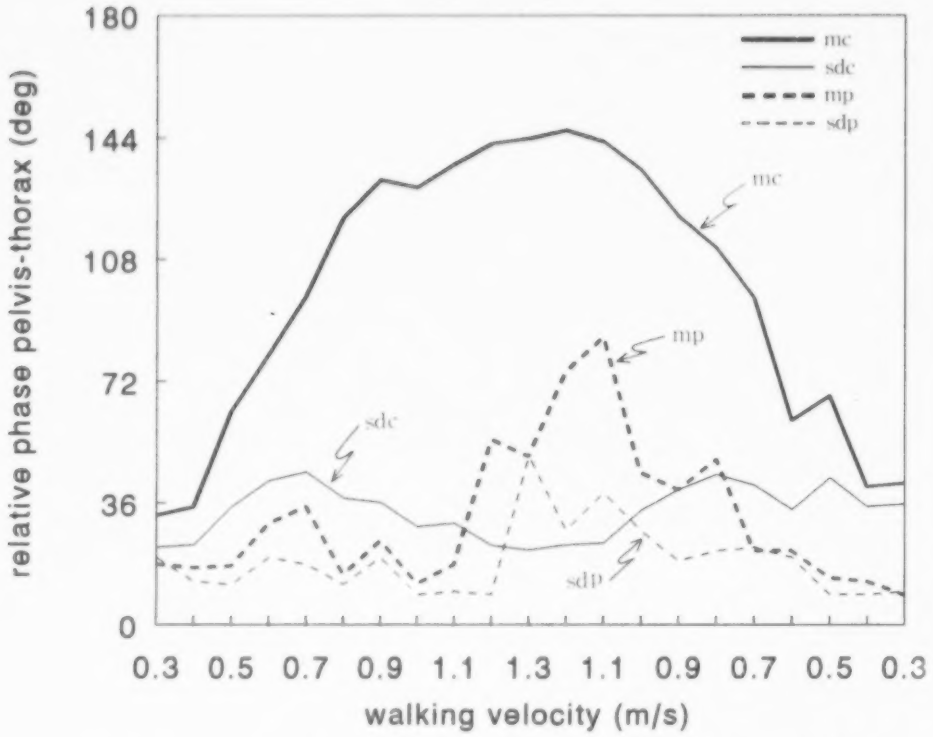


FIGURE 3 Changes in mean relative phase between pelvis and thorax for a control subject (solid lines) and a Parkinsonian patient (dashed lines) as a function of increasing and decreasing walking velocity on a treadmill. The mean relative phase over an entire stride cycle is plotted in bold lines, the stability in relative phase, expressed by the standard deviation, in thin lines. m = mean, sd = standard deviation, c = control, p = patient.

ities to a more out-of phase relation at higher velocities. The standard deviation of relative phase (thin solid line) increased (stability decreased) at intermediate velocities as compared to the standard deviation at low and high walking velocities. This indicates that there are two more or less stable coordination modes, with in between a region of lesser stability. This increased standard deviation at the intermediate range could be 'critical fluctuations' as predicted from synergetics. It should be noted that not all subjects do show this same pattern of stability changes; in some subjects no systematic changes in stability as a function of walking velocity were observed. These different transition mechanisms suggest multistability (i.e., multiple stable patterns) at lower walking velocities.

In the gait dynamics of patients suffering from a variety of neurological disorders it is generally observed that the movement patterns are less adaptive. We have proposed that the movement coordination problems in patients suffering from Parkinson's disease and hemiplegia after stroke can be related to a general inability to induce phase transitions. In Parkinsons' disease patients differences related to these transition

dynamics are observed (see for more detail, van Emmerik et al., 1993). In research on movement control problems in Parkinson's disease, the main clinical symptoms of rigidity, bradykinesia, and tremor have been assessed in isolation. From a dynamical perspective we have examined these symptoms in terms of a general inability to impose transitions in coordination patterns in these patients. We consequently searched for the most relevant control parameters that could be systematically scaled so that new coordination patterns can spontaneously emerge from the underlying dynamics.

An example of such a transition problem is depicted in Figure 3: in contrast to the changes in relative phase in the healthy subject, on systematic changes in the relative phase between pelvis and thorax were observed in a patient with Parkinsons's disease (see dashed lines). The relative phase remained in an almost in-phase relation at a variety of different velocities, although decreasing the velocity resulted in larger phase differences at comparable speeds than increasing velocity (hysteresis). In addition, there was a very low variability of relative phase, indicating high stability in the relative phase between pelvis and thorax, that did not change with walking speed.

In stroke patients movement coordination problems arise as a consequence of lateral asymmetries that result from a hemiplegia. But these coordination problems are not only related to arm and leg movements; the movement of the trunk is also severely affected as was shown in a dimensionless analysis by Wagenaar and Beek (1992). We recently investigated the effects of using an imposed step frequency as the control parameter on changes in trunk rotation. No large changes in trunk rotation were observed as a function of frequency, but the type of rhythm did seem to make a difference. When the subject was instructed to move both arms and legs to the rhythm of a metronome, the observed phase difference in the trunk between pelvis and thorax was larger than when the subject was instructed to only move his legs to the rhythm of the metronome. This larger phase difference is a more stable pattern, especially for locomoting at higher velocities where it is linked to a reduced spin in trunk rotation and an increased pelvic rotation to lengthen the stride.

Transitions in kinematics of upper and lower extremities

Craik et al. (1976) observed an 'abrupt' change in the frequency relations between upper and lower extremities as a function of walking velocity: below 0.75 Hz the frequency relation was 2:1, above 0.75 Hz the frequency relation was 1:1. Jackson et al. (1978) have suggested that this switch from a 2:1 to 1:1 frequency coupling might arise within the upper extremity due to period doubling in the oscillation of the forearm. These different frequency relations are related to changes in the relative phase between the two arms.

In our research (Wagenaar & van Emmerik, in press) we observed in 6 healthy subjects a general change from an in-phase or alternating pattern at lower and intermediate velocities to a more out of phase pattern at higher velocities. Similar stability characteristics were observed as in the trunk: at intermediate velocities (around 0.8–0.9 m/s) loss of stability could occur. These findings are consistent with frequency changes that can occur as a function of walking velocity. At walking velocities lower than 1.0 m/s the dominant peak frequency in the arm coincides with the step frequency

in the leg. At 1.0 m/s there is a transition to a synchronization with the stride frequency in the leg. Although stride and step frequency components are present at all walking velocities, the change from locking onto step to locking onto stride frequency occurs between 0.9 and 1.0 m/s.

Using the model of the simple gravitational pendulum (see equation 2), two coordinative modes with preferred frequency (0.9-1.1 Hz) were observed: one at lower walking velocities around 0.5 m/s in which the arms were locked onto the step frequency, and one at higher walking velocities around 1.2 m/s in which the arms were locked onto the stride frequency. The model predictions of the gravitational pendulum predicted the periodic data most accurately using an integer value of n=2 in equation (2). These data are consistent with earlier findings from Holt et al., (1990) who found a similar constant for the lower extremities while subjects walked at their preferred tempo. These data confirm Kugler and Turvey's (1987) proposed quantization of the gravitational field constant and suggest that the movement dynamics in human walking may, at least in part, be consistent with physical conservations. These two different modes were not always observed, however, but the data suggest multistability (the existence of more than one pattern) at the lower walking velocities.

Both stroke and Parkinson's patients showed less adapations in arm movements as a function of walking velocity or stride frequency as compared to normal controls. In Figure 4 the effects of an auditory rhythm (metronome) on the relative phase between the two arms are presented for a Parkinsonian patient and a control subject. Both were intructed to adapt a step frequency in tune with the rhythm. The control subject clearly shows a change to a more out of phase pattern at higher frequencies (a more stable pattern), but the patient does not make this transition at all.

That manipulations of control parameters such as walking velocity and imposed external rhythms can change pathological movement dynamics, is demonstrated in the effects of velocity on pathological arm tremor during treadmill locomotion. At low velocities (0.2 m/s), where arm swing was minimal, the dominant frequency in the power spectrum was the pathological tremor in the 4-6 Hz range (see Figure 5 upper right panel). Increasing the velocity reduced this pathological tremor, and at a about 0.8 m/s the pathological tremor virtually disappeared. The dominant tremor in the spectrum of frequencies was now the regular oscillatory frequency of the arm, which was closely coordinated and coupled to the rhythm of the leg (see Figure 5 middle panel). Interestingly, when walking velocity was subsequently decreased from 0.8 to 0.2 m/s, the pathological tremor did not reappear at lower velocities, and the dominant frequency in the arm was still synchronized with the oscillation in the leg (see Figure 5 lower panel). This is another example of the phenomenon of hysteresis in the control of locomotion. These observations reveal the plasticity in movement control and suggest that walking velocity is an important control parameter that can affect pathological tremors and oscillations during locomotion as predicted by the tremor models discussed above.

The data presented in the previous example indicate the flexibility in the movement control system and hysteresis in coordination of walking. Observed patterns are dependent on the nature of the control parameter, but also on the way the control

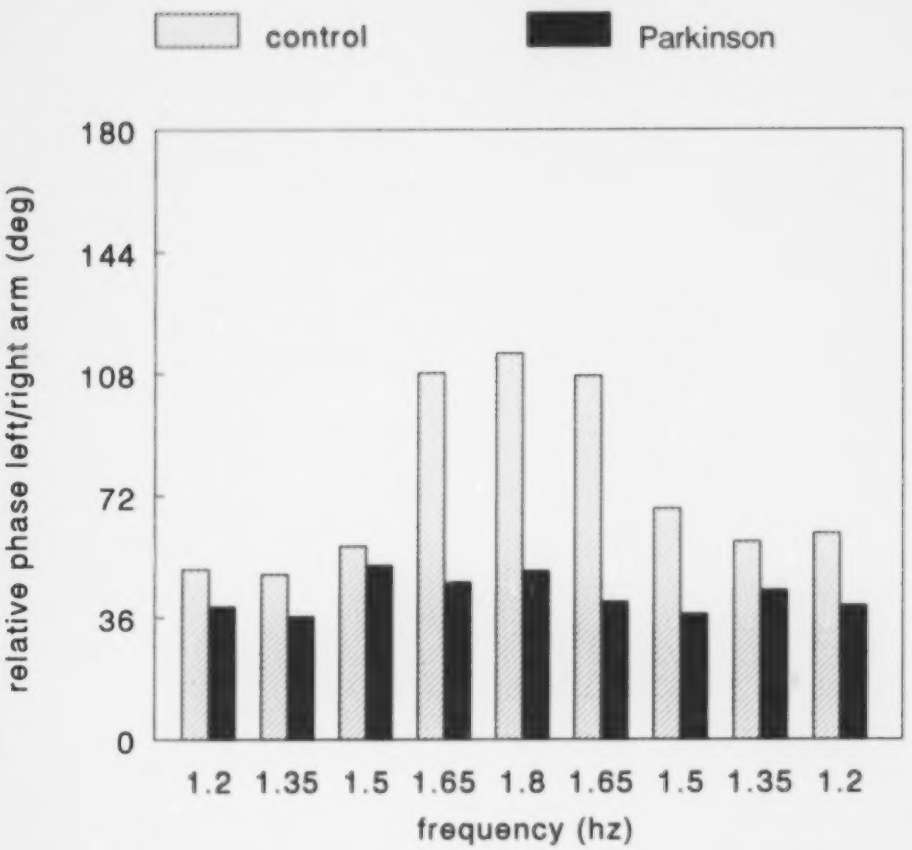


FIGURE 4 Changes in relative phase between left and right arm for a control subject and a patient with Parkinson's disease when systematically increasing and decreasing step frequency on a treadmill.

parameter is scaled, in this case whether walking velocity was increased or decreased. The data also support the predictions from logistic models of May (1977) and Akamatsu et al. (1986) in that scaling a single control parameter can systematically effect the nature of the dynamics.

The tools utilized also show the movement impairments of these patient groups and the general inability to change pattern, but suggest that with the right choice of control parameter transitions can indeed be elicited. The transition problems can arise due to an inability to impose *functional* asymmetries that are, according to Schöner et al. (1990), essential in inducing a pattern change. The pathological asymmetries in stroke patients (hemiparesis) and extreme symmetries often observed in Parkinsonian patients (rigidity) could very well interfere with imposing these functional asymmetries (e.g., disbalance when going from standing to walking).

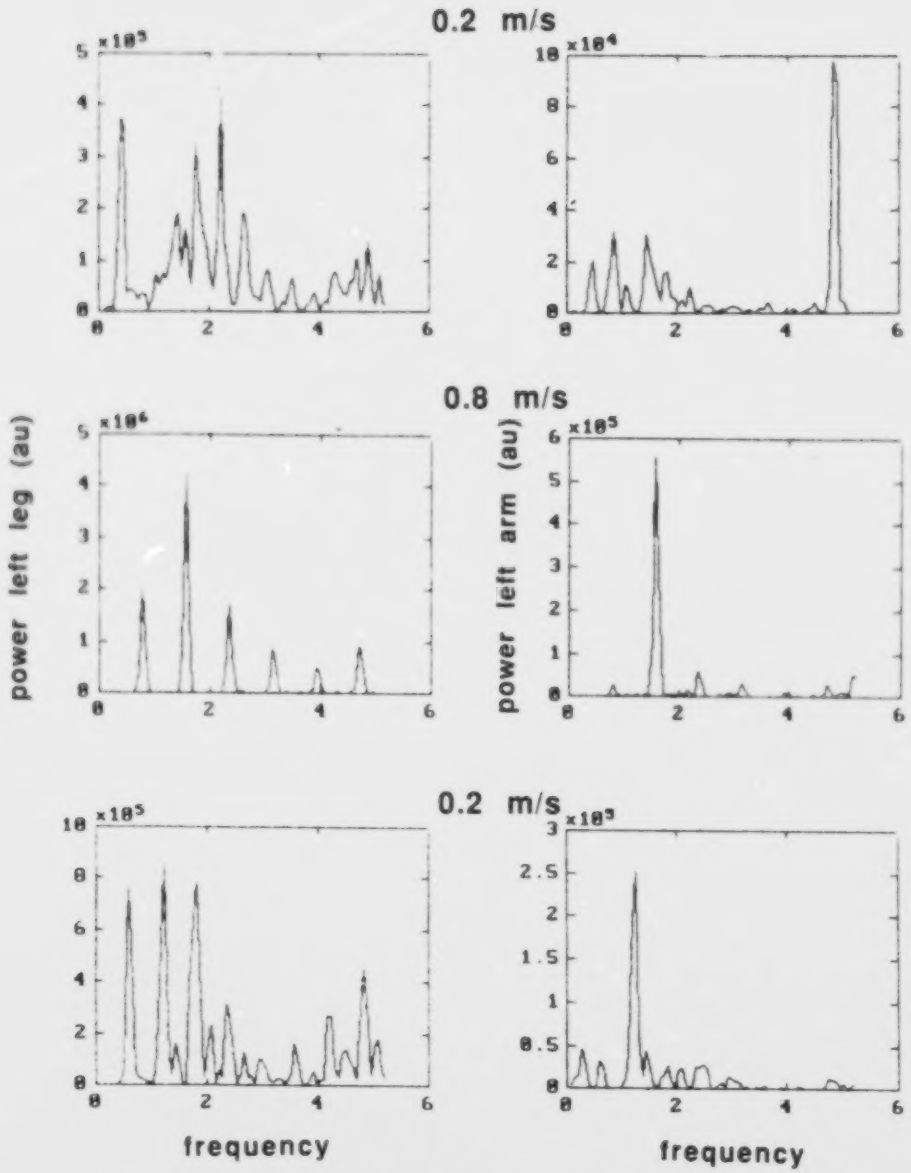


FIGURE 5 Resetting of Parkinsonian tremor during locomotion on treadmill while systematically increasing walking velocity. from 0.2 m/s (upper panel) to 0.8 m/s (middle panel), and decreasing again to 0.2 m/s (lower panel). Data present the different frequency components in the movements of the left leg (left panels) and the left arm (right panels).

Implication for Motor Develoment

Relative phase dynamics

The tools from dynamical systems theory as presented adove can also be applied to the study of developmental transitions in locomotory patterns. A number of studies have emerged that examined the dynamics of movement coordination in young infants and children (e.g., Clark et al., 1988; Thelen, 1986). Based on relative phase analyses of interlimb and intralimb coordination, Clark and colleagues (e.g., Forrester at al., 1993) maintain that infants achieve adult coordination patterns in both walking and running. They identified the relative phase relation between footfalls as a suitable order parameter, but could not identify systematic differences between infants and adults. Both revealed on the average a 50% phase lag between the limbs' cycles. The only difference observed was that younger independent walkers with less than 3 months walking experience had higher variability in the relative phase measure. Similar observations were made concerning relative phase measures in intralimb coordination in the lower extremity. Discrete relative phase analyses of thigh and shank angles revealed similar phase angles between adults and infants at different developmental stages for both walking and running.

The conclusions of Forrester et al. (1993) regarding observed similarities in relative phase dynamics between adults and infants seem preliminary in light of the data presented above. A 50% phase lag between consecutive footfalls probably reflects more the constraints imposed on the locomotory sequence than a true difference in dynamics. Namely, in locomoting forwards one would only expect deviations from the 50% phase lag in case of clear left right asymmetries. In addition, interlimb relative phase dynamics might differ between adults and infants when we take the dynamics of the whole body into account such as relative phase relations between upper and lower extremities or between the two arms.

Finally, the analyses were based on relative phase dynamics in the sagittal plane of motion. As our own research has demonstrated, changes in relative phase in trunk dynamics occur also in the transverse plane of motion. It is well possible that extension of relative phase analyses in infant trunk motion to these other planes of motion will reveal important differences as compared to adult patterns, and might be a distinguishing feature in movement pathologies. Indeed, Sutherland et al. (1980) observed an increased external rotation of the hip, and increased pelvic tilt in young infants as compared to adults. Given the style of locomotion of young infants, in which the movement of the center of gravity is proportionally larger in the transverse plane of motion and the infants' weight is more explicitly shifted from left to right side, changes in the relative phase dynamics in the transverse or frontal planes of motion may be expected.

Therapeutic strategies

Scholz (1990) discusses therapeutic strategies inspired by the dynamical systems approach in children with cerebral palsy. These children often locomote on all fours using a hopping pattern ('bunny hop'), a quadrupedal pattern of interlimb coordination where limbs at the same girdle (pelvis, shoulder) move in phase, and limbs at different

girdles move out-of-phase. As Scholz indicates, one goal of movement therapy might be to induce a reciprocal pattern. Relative phase measures between the four limbs could be relevant order parameters to evaluate coordination changes. Possible control parameter could again be locomotory speed. Children who exhibit this hopping pattern appear extremely stiff, and this increased stiffness might make functional asymmetries and switching to a new coordination pattern difficult. One of the important aspects of dynamical systems theory is to elicit new patterns without the child's conscious effort. Control parameters play a crucial role in this process, and failure to observe treatment effects might be the result of an inappropriate choice of control parameter or, more importantly, not taking the control parameter through a sufficient range so that critical values are reached and, possibly, a pattern change.

In the preceding example, if locomotory speed turns out to be an important control parameter that can change the hopping pattern (for example by systematically manipulating speed on a treadmill), then the old pattern can be destabilized by the systematic manipulation of speed in which different patterns (i.e., the reciprocal pattern) emerge. Exercising at specifically chosen speeds can act to destabilize the old pattern, which is considered very stable given the high stiffness in these children. The result could be an increase of fluctuations in performance (i.e., in relative phase relations), which is considered essential in the creation of new patterns. This stability can be evaluated by measuring the fluctuations in relative phase or by assessing the recovery from an externally imposed mechanical perturbation. The recovery time ('local relaxation time') following such a pertubation is an indicator for the amount of stability in the system; a long recovery time implies an unstable system, a short recovery time a stable system. Close to a phase transition the relaxation time following a pertubation increases, signalling an imminent phase transition.

In summary, therapeutic strategies based on dynamic systems theory should focus on: 1) identifying the relevant order parameters that characterize the coordination dynamics; 2) identifying aspecific control parameters that can induce a pattern change; 3) manipulating the control parameters through a sufficient range so that instability emerges, a necessary prerequisite for the formation of new, stable patterns; and 4) using external rhythms or oscillators to establish synchronization or entrainment between different body segments.

REFERENCES

Abraham, R. H., & Shaw, C. D. (1984). *Dynamics—The geometry of behavior—Part 1: Periodic behavior*. Santa Cruz, CA: Aerial Press.

Adams, J. J. (1971). A closed-loop theory of motor learning. *Journal of Motor Behavior*, **3**, 111-149.

Akamatsu N., Hannaford B., & Stark L. (1986). An intrinsic mechanism for the oscillatory contraction of muscle. *Biological Cybernetics*, **53**, 219-227.

Andriacchi T. P., Ogle J. A., & Galante J. O. (1977). Walking speed as a basis for normal and abnormal gait measurements. *Journal of Biomechanics*, **10**, 261-268.

Bernstein, N. (1967). *The coordination and regulation of movements*. London: Pergamon.

Cappozzo, A. (1981). Analysis of the linear displacement of the head and trunk during walking at different speeds. *Journal of Biomechanics*, **14**, 411-425.

Clark, J. E., Whitall, J., & Phillips, S. J. (1988). Human inter-limb coordination: The first 6 months

of independent walking. *Developmental Psychobiology*, **21**, 445-456.

Craik, R., Herman, R.M., & Finley, F.R. (1976). The human solutions for locomotion: Interlimb coordination. In R.M. Herman, S. Grillner & P.S.G. Stein (Eds.), *Neural Control of Locomotion* (pp. 51-63). New York: Plenum Press.

Feldman, A.G. (1986). Once more on the Equilibrium Point hypothesis (Lambda model) for motor control. *Journal of Motor Behavior*, **18**, 17-54.

Forrester, L.W., Phillips, S.J., & Clark, J.E. (1993). Locomotor coordination in infancy: the transition from walking to running. In G.J.P. Savelsbergh (ed.), *The development of coordination in infancy*. Amsterdam: Elsevier.

Gibson, J.J. (1979). *The ecological approach to visual perception*. Boston: Houghton Mifflin.

Glass L., Mackey M.C. (1988). *From clocks to chaos: the rhythms of life*. Princeton, New Jersey: Princeton University Press.

Goldberger A.L., Rigney, D.R., West B.J. (1990). Chaos and fractals in human physiology. *Scientific American*, February.

Haken, H. (1977). *Synergetics: an introduction. Nonequilibrium phase transitions and self organization in physics, chemistry, and biology*. Heidelberg: Springer.

Haken, H., Kelso, J.A.S., & Bunz, H. (1985). A theoretical model of phase transitions in human hand movements. *Biological Cybernetics*, **51**, 347-356.

Holt, K.G., Hamill, J., & Andres, R.O. (1990). The force driven harmonic oscillator as a model for human locomotion. *Human Movement Science*, **9**, 55-68.

Jackson, K.M., Joseph, J., & Wyard, S.J. (1978). A mathematical model of arm swing during human locomotion. *Journal of Biomechanics*, **11**, 277-289.

Kelso, J.A.S., Scholz, J.P., & Schöner, G. (1986). Nonequilibrium phase transitions in coordinated biological motion: Critical fluctuations. *Physics Letters A*, **134**, 8-12.

Kugler, P.N. (1986). A morphological perspective on the origin and evolution of movement patterns. In M. Wade, & H.T.A. Whiting (Eds.), *Motor skill acquisition in children: Aspects of coordination and control* (pp. 459-525). The Hague: Martinus Nijhoff.

Kugler, P.N., & Shaw, R.E. (1990). Symmetry and symmetry breaking in thermodynamic and epistemic engines: A coupling of first and second laws. In H. Haken (Ed.), *Synergetics of cognition*. Berlin, Heidelberg, New York: Springer.

Kugler, P.N., Shaw, R.E., Vicente, K.J., & Kinsella Shaw, J. (1990). Inquiry into intentional system: I: Issues in ecological physics. *Psychological Research*, **52**, 98-121.

Kugler, P.N., Kelso, J.A.S., & Turvey, M.T. (1980). On the concept of coordinative structures as dissipative structures: I. Theoretical lines of convergence. In G.E. Stelmach, & J. Requin (Eds.), *Tutorials in motor behavior* (pp. 3-47). Amsterdam: North-Holland.

Kugler, P.N., Kelso, J.A.S., & Turvey, M.T. (1982). On the control and coordination of naturally developing systems. In J.A.S. Kelso, & J.E. Clark (Eds.), *The development of movement control and coordination* (pp. 5-78). New York: Wiley.

Kugler, P.N., & Turvey, M.T. (1987). *Information, natural law, and the self assembly of rhythmic movement*. Hillsdale, NJ: Erlbaum.

Larsson L.E., Odenrick P., Sandlund B., Witz P., & Oberg A. (1980). The phases of the stride and their interation in human gait. *Scandinavian Journal of Rehabilitation Medicine*, **12**, 107-112.

May R. (1976). Simple mathematical models with very complicated dynamics. *Nature*, **78**, 459-467.

Murray M.P., Sepic S.B., Gardner G.M., & Downs W.J. (1978). Walking patterns of men with Parkinsonism. *American Journal of Physical Medicine*, **57** (6), 278-294.

Nicolis, G., & Prigogine I. (1977). *Self-organization in equilibrium systems: From dissipative structures to order through fluctuations*. New York: Wiley.

Pennycuick, C.J. (1975). On the running of the Gnu (Connochaetes Taurinus) and other animals. *Journal of Experimental Biology*, **63**, 775-799.

Prigogine, I. (1980). *From being to becoming: time and complexity in the physical sciences*. New York: W. H. Freeman.

Prigogine, I., & Stengers, I. (1984). *Order out of chaos*. New York: Bantam.

Schmidt, R. A. (1975). A schema theory of discrete motor skill learning. *Psychological Review*, **82**, 225–261.

Scholz, J. P. (1990). Dynamic pattern theory—Some implications for therapeutics. *Physical Therapy*, **70**, 827–842.

Schöner, G., & Kelso, J. A. S. (1988). Dynamic pattern generation in behavioral and neural systems. *Science*, **239**, 1513–1520.

Schöner G., Jiang W. Y., Kelso J. A. S. (1990). A synergetic theory of quadrupedal gaits and gait transitions. *Journal of Theoretical Biology*, **142**, 359–391

Soodak, H., & Iberall, A. S. (1978). Homeokinetics: A physical science for complex systems. *Science*, **201**, 579–582.

Sutherland, D. H., Ohlsen R., Cooper L., & Woo S. L. Y. (1980). The development of mature gait. *Journal of Bone and Joint Surgery*, **62A** (3), 336–353.

Thelen E. (1986). Treadmill elicited stepping in seven month old infants. *Child development*, **57**, 1498–1506.

Thompson, J. M. T., & Stewart, H. B. (1986). *Nonlinear dynamics and chaos*. Chicester: Wiley.

Turvey, M. T. (1990). Coordination. *American Psychologist*, **45**, 938–953.

Van Emmerik R. E. A. & Wagenaar R. C. (1992). Qualitative changes in the walking mode of healthy and neurologically impaired individuals. In M. Woollacott & F. B. Horak (Eds.), *Posture and gait: Control mechanisms* (p. 168–171). Portland: University of Oregon Press.

Van Emmerik, R. E. A., Wagenaar, R. C., & Wolters, E. Ch. (1993). Dynamics of movement coordination in Parkinson's disease. In E. Ch. Wolters & P. Scheltens (Eds.), *Mental dysfunction in Parkinson's disease* (p 69–91). Dordrecht, The Netherlands: ICG Printing.

Von Bertalanffy, L. (1968). *General systems theory*. New York: Braziller.

Waddington, C. H. (1970). Concepts and theories of growth, development, differentiation and morphogenesis. In C. H. Waddington (Ed.), *Towards a theoretical biology*: Vol. 3. Drafts (pp. 177–197). Edinburgh: Edinburgh University Press.

Wagenaar R. C. & Beek W. J. (1992). Hemiplegic gait: A kinematic analysis using walking speed as a basis. *Journal of Biomechanics*, **25**, 1007–1015.

Wagenaar R. C. & van Emmerik, R. E. A. (in press). The Dynamics of pathological gait: Stability and adaptability of movement coordination. *Human Movement Science*.

Winfree A. T. (1980). *The geometry of biological time*. Heidelberg: Springer.

Winfree A. T. (1987). *The timing of biological clocks*. New York: Scientific American Library.

A NATURAL PHYSICAL PERSPECTIVE ON THE DEVELOPMENT OF INFANT EYE-HAND COORDINATION: A SEARCH FOR THE LAWS OF CONTROL

Geert J. P. Savelsbergh and
John van der Kamp
Free University, Amsterdam

The goal of the article is to describe a research paradigm with respect to eye-hand coordination. Basic concepts of ecological psychology (information and affordances), of non-linear dynamics (order parameter, control parameter and stability), and of the natural physical approach (the laws of control) are discussed. The article will conclude with a description of the research program as currently conducted within the proposed research paradigm.

Key words: Information, affordances, order and control parameters, stability, laws of control.

Introduction[1]

The starting point of our research program concerning the development of infant's eye-hand coordination is the natural physical approach based on the work of Bernstein (1967), Gibson (1979) and Kugler, Kelso and Turvey (1982). According to the coordinative structure theory proposed by Kugler et al. (1982), development of coordination is brought about by changes in the constraints imposed upon action. Three categories of constraints have been proposed: organismic (e.g., nerve system), task (e.g., reaching with one hand) and environmental (e.g., large object) (Newell, 1986). These different constraints do not operate in isolation, but interact with each other, leading to a task-specific organisation of the coordination pattern. Hence, constraints have to be defined for the organism-environment complex: properties of the organism and the environment collectively determine movement possibilities.

The purpose of the paper is to show that perception and movement should be considered as inseparable (Kugler & Turvey, 1987: Savelsbergh & Van der Kamp 1993). This coupling of perception and movement is approached from a developmental perspective. To lay a basis for this, the concepts of direct perception (Gibson, 1979: information and affordances), of non-linear dynamics (Zanone, Jeka & Kelso, 1993:

[1] Portions of this article have been published in a more extensive form by Savelsbergh & Van der Kamp (1993) as Chapter 11 in G. J. P. Savelsbergh (Ed.), *The Development of coordination in infancy* (pp. 289-317) North Holland: Elsevier.

order and control parameters, stability) and of the natural physical approach (Kugler, 1986: laws of control) are discussed. The article will conclude with a description of the research program with respect to eye-hand coordination as currently conducted in our lab.

1 A new approach to perception and movement

One of James Gibson's (1979) most famous citations is 'We must perceive in order to move, but we must also move in order to perceive' (p. 223). Information guides the movement, and through movement new information is generated and becomes available to the actor. What precisely is meant by 'information'?

1.1. Information

Gibson's (1979) ecological approach to visual perception is also known as direct perception. The word 'direct' refers to the fact that objects, places and events in the environment are unambigiously specified in the optic array. This information can be picked up by the perceiver without the need to interpret it. Hence, no cognitive mediation is needed in order to make perception meaningful. In 1988, his wife and colleague Eleanor Gibson wrote:

> The old view of perception was that "input" from stimuli fell upon the retina, creating a meaningless image composed of unrelated elements. Static and momentary, this image had to be added to, interpreted in the light of past experiences, associated with other images, etc. Such a view of perception dies hard, but die it must. There is no shutter on the retina, no such thing as a static image. Furthermore, perceiving is active, a process of obtaining information about the world....We don't simply see, we look. When we seek information in an optic array, the head turns, the eyes turn to fixate, the lens accommodates to focus, and spectacles may be applied and even adjusted by head position for far or near looking (p. 5).

In this view the information in the optic array is not static in time and space. It specifies events, place and objects. Therefore, when a child detects the information, she or he perceives events and not some kind of discrete stimulus that has to be interpreted. This concept of information is closely related to the concept of affordances.

1.2. Affordances

In Gibson's (1979) approach the word 'affordances' is a central concept. It expresses the relation between perceiving and acting:

> The affordances of the environment are what it offers the animal, what it provides or furnishes, either for good or ill. The verb to afford is found in the dictionary, but the noun affordance is not. I have made it up. I mean by it something that refers to both the environment and the animal in a way that no existing term does. It implies the complementarity of the animal and the environment' (p. 127).

Affordances relate to possibilities for action of an organism in a particular environment. Therefore, they relate to the perceiver's own potential action system, which

implies the use of a body-scaled and not an absolute metric (e.g., meters, kilogrammes etc.) for perceiving. 'Body-scaled' means that the coordination pattern is determined by the ratio between a metric of the action space and a metric of the actor (body dimension). For example, for an actor who wants to climb stairs, the coordination pattern is specified by the ratio between the tread height (action space) and the actor's leg length (metric of the actor) (Warren, 1984). Another example is provided during the act of grasping of an object. When the object is small, it is possible to take the object with one hand. When the object is too big for one hand, two hands are needed. When the ratio between hand size (metric of the actor) and object size (action space) reaches a critical ratio, a new coordination pattern emerges, the actors shift from one-handed to two-handed grasping. In the case of stair climbing another pattern is shown when the tread height becomes too high (e.g., normal tread height for a young child). The child crawls instead of walks. The question that now arises is: how do we detect these affordances? By picking up the information specifying and guiding the movement, affordances are detected. An affordance refers to the fit between the information and the action.

1.3. The detection of affordances

Crucial in the detection of affordances is the active exploration of the environment (see Van der Kamp & Savelsbergh, this volume). Exploratory activity (e.g., moving) reveals information and therefore affordances. During development, organismic constraints (depth vision, muscle power etc.) change very quickly and therefore the exploratory possibilities change dramatically. Consequently, infants start crawling, the number of action possibilities increases, leading to the discovery of new information and the detection of affordances. Furthermore, by exploratory activities infants become more sensitive to relevant information which guides their actions.

In sum, exploration is not some kind of trial and error behaviour, but controlled behaviour. As Michaeland Carello (1981) points out:

> 'Exploration (attention) is not an unconscious sifting through and subsequent rejection of most inputs: It is directed control of what will be detected' (p. 70).

Exploration is goal-directed in the sense that it reveals the coupling between information and action or between organism and environment (Van der Kamp & Savelsbergh, this volume). Similarly, Kugler, Kelso and Turvey (1982) argue that stable modes of action (e.g., walking) emerge from the underlying dynamics of the organism-environment system and is guided by information specific to these dynamics. In this respect the concept of laws of control is relevant. However, before discussing these laws, some concepts from non-linear dynamic systems theory need to be discussed.

2. Dynamic systems

Dynamic systems theory provides tools to identify patterns of behaviour, to describe changes in these patterns and to investigate what leads to these changes (Zanone, Kelso & Jeka, 1993). In this respect, three main concepts will be discussed:

order and control parameters, and stability.

2.1. Order and control parameters, stability

An order parameter or collective variable is the parameter that captures the behaviour (coordination pattern), while a control parameter is the parameter that leads the system through different coordination patterns. Within this approach, the behavioural pattern is regarded as a stable collective state attained by the system under certain constraints (boundary conditions) and informational settings (Zanone et al., 1993). When the control parameter passes through a critical point, a previous coordination pattern which was stable in organisation becomes unstable causing a sudden discrete transition to a qualitatively different, stable coordination pattern. Let's have a look at the same example as in section 1.2. The coordination pattern for grasping an object is dependent on the ratio of object size hand size. When the object is larger than the hand, it will be grasped with two hands (stable mode). During development the hand will become larger (in fact a scaling up) which implies that the ratio of object hand size changes. At a certain ratio (critical point) the object will be grasped with one hand, and another time with two hands, that is, there is a loss of stability. If the hand grows larger, the object will be constantly grasped with one hand, that is, a new stable mode emerged. Hence, with respect to development, patterns of coordination become unstable and even disappear and new patterns of coordination suddenly emerge and become stable. We will use this way of describing developmental changes in coordination patterns and describe two general laws of control in section 3.2. In the previous section, we argued that exploratory behaviour is essential in detecting affordances. In the next section we explain the relation between exploratory behaviour and stability.

2.2. Exploratory behaviour and stability in the workspace

According to Newell and co-workers (Newell et al., 1989), developmental changes in coordination arise from explorations of the perceptual motor workspace. The workspace evolves from the circular relations between movement and perception (or informational processes). It is regarded as a generic concept, in which both the building blocks (equilibrium or attractor regions which are asymptotically stable solutions of the collective variable dynamics) and the exploratory behaviour to discover critical regions (border of stability and instability) in the workspace are universal. Exploration of these workspaces is guided by constraints that arise from the configurations of the field processes that characterise the space. In other words, the information organisms utilise to explore the workspace is embedded in the form and layout of the gradient and equilibrium (attractor) regions that characterise that space. By means of exploratory behaviour, the control parameter can be scaled up or down to a critical point, and stability and instability regions can be discovered. By discovering these regions, exploitation of the stabilities and instabilities can be carried out (also by means of exploratory behaviour), which will lead to an effective solution for accomplishing a specific task.

Both from an ecological psychological approach and from a dynamic systems

approach, exploratory behaviour is very important. In the former, it is important for the detection of affordances, in the latter, for the detection of critical regions. In the next section we bring these two perspectives together.

3. Bringing ecological psychology and dynamic systems together: a natural physical approach

Kugler and Turvey (1987; Kugler 1986) proposed laws of control which express the lawful relationship between perception and action. Put another way, the laws of control involve the relationship between kinematic optic flow fields (perception) and the kinetics of force fields (movement) (see also Savelsbergh & van Emmerik, 1992; Savelsbergh & Van der Kamp, 1993).

3.1. Laws of control

The relations between information that constrains movement and movement that generates information are consistent with, but *not reducible* to, natural laws of physics. Kugler and Turvey (1987) proposed two 'general' ecological laws of control to describe these relationships:

Law of Ecological Optics $flow = F(force)$ and
Law of Specification $force = F(flow)$

These laws identify the parameters of movement in the (kinetic) force field that are uniquely specified by the information in the (kinematic) flow field and vice versa.

Warren, Young and Lee (1986) investigated the visual control of running over an irregular surface and proposed such a law for this task. While running, the runner has to adjust step length to the (sometimes changing) demands of the support terrain. The step length of the runner is determined by the amount of vertical impulse: a large impulse causes a long step length (force). Furthermore, while running, the approaching irregularities of the surface provide an optical expansion on the retina (flow). The inverse of the relative rate of dilation of these approaching expanding optical contours generated in the optical array specifies the time of contact between the observer and the environment. This optical variable has become known as the *tau*-variable (Lee, 1980; Savelsbergh et al., 1991, 1993). The Warren et al. study (1986) demonstrated that the required duration of the step (and therefore step length) as regulated by the amount of impulse, I, between two upcoming targets is specified by the difference in time to contact between two targets (difference between the two tau's=delta T):

Impulse = mass × gravity × delta T
(mass × gravity is a constant)

This 'ecological' law specifies the relation between a vertical impulse (an action variable) and an optical variable tau (a perceptual variable).

3.2. Developmental laws

By analogy with the aforementioned laws of control, two developmental laws are proposed by the authors. These general developmental laws bring together the con-

cepts of information and affordances (section 1.1 and 1.2) and the concept of stability (section 2.1.). The two general laws are, for a given time during development and a certain set of constraints:

Law of Possibility *affordance* = *F* (*stable mode of action*)
Law of Stability *stable mode of action* = *F* (*affordance*)

Discovering of new affordances will lead to new stable modes of action (or order parameters). These stable modes of action (i.e., stability in a particular coordination pattern) are effective solutions for a particular task under given constraints. Changes in stable mode of action (due to the scaling up or down of a control parameter) will lead to the discovery of new affordances. Savelsbergh and Van der Kamp (1993) mentioned the example of an infant who needs both hands to pick up a large object. If s/he is not able to sit without support (i.e., instability of this particular coordination pattern), the infant will not be able to grasp the object. However, in ontogenetic time, the postural control will improve (i.e., the control parameter will scale up beyond a critical point) so that the infant will be able to sit without support (i.e., there will be stability of this particular coordination pattern). At this point, infants will discover that the ball is graspable with two hands (i.e., there is a new affordance).

It is important to note the way in which new affordances are discovered and new stable modes of action are acquired. This is achieved by a continuous exploration of the perception movement cycle (Newell et al.'s perceptual motor workspace), whereby the relevant coupling of information and movement is discovered (section 2 and Van der Kamp & Savelsbergh, this volume). This is in agreement with Warren's (1990) suggestion that dynamic stabilities and laws of control are discovered and exploited in the course of development. In other words, exploration serves to permit the laws of control to be discovered for a particular task.

4. Conclusions and the research program for eye hand coordination

In the research paradigm outlined in this paper, development is seen as a continuous attunement of the actor to the environment accomplished by repeated exploration of the perception movement cycle. This exploration is constrained by internal and external constraints and leads to task specific organisations. The important issue is to investigate how this coupling between perception and movement develops and to discover their lawful relationships.

The research program concerning infant eye hand coordination within the natural physical approach focuses on describing the development of infants reaching and grasping in terms of transitions of order parameters and the discovery of the control parameters inducing these transitions (underlying mechanism) (Wimmers, Savelsbergh, Beek & Hopkins, this volume). Further, it aims to discover the relevant informational (visual and proprioceptive; e.g., Savelsbergh et al. 1991, 1993) and movement constraints (strength; e.g., Out & Savelsbergh, this volume) controlling reaching and grasping behaviour and the way in which infants explore the perception movement cycle in order to acquire a stable reaching and grasping pattern (Van der Kamp & Savelsbergh, this volume).

REFERENCES

Bernstein, N. (1967). *The coordination and regulation of movement.* New York: Pergamon Press.

Gibson, E. J. (1988). Exploratory behavior in the development of perceiving, acting, and the acquiring of knowledge. In M. R. Rosenzweig & L. W. Porter (Eds.), *Annual review of psychology* (pp. 1-41). Palo Alto, California: Annual Review Inc.

Gibson, J. J. (1979). *The ecological approach to visual perception.* Boston: Houghton Mifflin.

Kamp, J., van der, & Savelsbergh, G. J. P. (this volume). *Exploring exploration in the development of action.*

Kugler, P. N., & Turvey, M. T. (1987). *Information, natural law, and the self assembly of rhythmic movements.* Hillsdale (NJ): Erlbaum.

Kugler, P. N., Kelso, J. A. S., & Turvey, M. T. (1982). On the control and coordination of naturally developing systems. In J. A. S. Kelso & J. E. Clark (Eds.), *The development of movement control and coordination* (pp. 5-78). New York: John Wiley and Sons.

Lee, D. N. (1980). Visuo motor coordination in space-time. In G. E. Stelmach & J. Requin (Eds.), *Tutorials in motor behavior* (pp. 281-293). Amsterdam: North Holland.

Newell, K. M. (1986). Constraints on the development of coordination. In M. Wade & H. T. A. Whiting (Eds.), *Motor development in children: Aspects of coordination and control* (pp. 341-360). Dordrecht: Martinus Nijhoff.

Newell, K. M., Kugler, P. N., Emmerik, R. E. A. van, & McDonald, P. V. (1989). Search strategies and the acquisition of coordination. In S. A. Wallace (Ed.), *Perspectives on the coordination of movement* (pp. 85-122). Amsterdam: North Holland.

Out, L., & Savelsbergh, G. J. P. (this volume). *The role of strength in the development of reaching.*

Savelsbergh, G. J. P., & Emmerik, R. E. A., van (1992). Dynamic interactionism: From co-regulation to the mapping problem. *Human Movement Science,* **11**, 443-451.

Savelsbergh, G. J. P., & Kamp, J. van der (1993). The development of infants reaching, grasping, catching and posture: A natural physical approach. In G. J. P. Savelsbergh (Ed.), *The development of coordination in infancy* (pp. 289-317). Amsterdam: North-Holland.

Savelsbergh, G. J. P., & Kamp, J. van der (under review). *The effect of gravity on infant reaching.*

Savelsbergh, G. J. P., Whiting, H. T. A., & Bootsma, R. J. (1991). 'Grasping' Tau. *Journal of Experimental Psychology: Human Perception and Performance,* **19**, 315-322.

Savelsbergh, G. J. P., Whiting, H. T. A., Pijpers, J. R., & Santvoord, A. M. M. (1993). The visual guidance of catching. *Experimental Brain Research,* **93**, 146-156.

Warren W. H. (1990). The perception action coupling. In H. Bloch & B. I. Bertenthal (Eds.), *Sensory motor organizations and development in infancy and early childhood* (pp. 23-37). Dordecht: Kluwer Academic Publishers.

Warren, W. H. (1984). Perceiving affordances: Visual guidance of stair climbing. *Journal of Experimental Psychology: Human Perception and Performance,* **10**, 683-703.

Warren, W. H., Young, D. S., & Lee, D. N. (1986). Visual control of step length during running over irregular terrain. *Journal of Experimental Psychology: Human Perception and Performance,* **12**, 259-266.

Wimmers, R. H., Savelsbergh, G. J. P., Beek, P. J., & Hopkins, B. (this volume). *Are there phase transitions in the development of eye-hand coordination?*

DEVELOPMENT OF COORDINATION OF SPONTANEOUS LEG MOVEMENTS.

Juliëtte Vaal
Knoek van Soest and Brian Hopkins
Free University, Amsterdam

A striking feature of the early human motor repertoire consists of spontaneous kicking movements. The first part of this article gives an overview of the origins of locomotor behaviour in vertebrates with special reference to its neural organization. The second part concentrates on experiments on the development of leg movements in human infants. Different attempts have been made to explain the origins of the observed changes in development. Taking this into consideration, we present the setup of our research project and the releated hypotheses.

"Without being nursed or even meeting any adult, many lower vertebrates can develop the appropriate locomotor movements and the strategy for how to adapt to the environment. Many mammals can walk and even run minutes after birth. Other mammals, including the cat and rat are immature when born, but even when raised in isolation, they mature and become able to walk and run." (*Grillner, 1981*)

Origins of vertebrate locomotor behaviour

One of the greatest problems in controlling complex movements is how to reduce the enormous number of degrees of freedom within the animal or its environment (Bernstein, 1967). The problem is equivalent to trying to solve more unknowns (animal-environment details) than there are equations (desired positions). In tasks that have proven to be important during evolution, like locomotion, there are indications that within the nervous system there exist certain structures that can be held responsible for this required reduction of degrees of freedom. In their classical study, Wiersma & Ikeda (1964) found five interneurons in the abdominal ganglia of the crayfish that could be held responsible for the swimmeret movements that were observed. They called these five neurons 'command neurons' which were thought to control the activity of the whole ganglia. In this way, low-dimensional command neurons can be held responsible for high dimensional movements on the output side. Many questions remain about the exact nature of these degrees of freedom reducing 'one-to-many maps'. An important aspect is the role of feedback.

In the first half of this century, naturalists interested in the Central Nervous System (CNS) formulated two alternative, but not mutually exclusive, hypotheses, about how locomotor movements are generated. The first is that centres within the nervous system are responsible for activating and coordinating the muscles involved in a movement according to a *Central Pattern Generator* (*CPG*). This CPG can be regard-

ed as a cluster of neurons with a variable amount of connections that have variable weights. An important feature of the CPG is that the dimension of the output is higher than the dimension of the input and that it can generate output without any sensory feedback. The second hypothesis is that peripheral feedback elicits a cyclical movement by a "reflex chain", i.e., an external signal causes a contraction in a muscle or muscle group; this contraction generates sensory information which serves as a trigger for the next contraction etc. (e.g., Grillner, 1981).

These two hypotheses can be regarded as extreme points on a continuum of motor control: at one side of the continuum, motor control is regarded to be an open-loop process (CPG hypothesis), at the other side, motor control is regarded as a closed-loop process (reflex chain hypothesis). We think there is another continuum on which the reflex chain hypothesis and the CPG concept are extremes, namely a continuum from inflexibility to flexibility. By 'flexibility' we mean that it is possible for a system to change the input/output relation. We regard a CPG as flexible in that it is possible to make or break connections between neurons and to strenghten or weaken synaptic weights. The reflex chain, on the other hand, is in our view less easily adaptable. The simple topology is a constraint on flexibility.

It was Brown (1914) who explicitly attacked the reflex theory. He anaesthesised cats and observed that complex rhythmical movements occur at a depth of narcosis where reflexes are abolished. Brown suggested that rhythmical movements are 'conditioned by the balanced activation of antagonistic and linked efferent cycles (or half centres)', exerting mutual inhibition (e.g., Meijer, 1993). Also von Holst (1973) criticised the reflex chain theory. He observed that excitatory patterns sometimes occurred simultaneously, which challenged the idea of chain-like patterns. It should be noted that this argument is only true if the reflex chain is regarded as a one-dimensional connection.

Von Holst performed experimental tests on deafferented or isolated spinal cords and established their rhythm generating capacities: an indication that a central rhythm generating network located within the spinal cord indeed exists. Other support in favour of the CPG hypothesis comes from experiments by Cohen and Wallén (1980). They were able to show that, under appropriate conditions, the isolated lamprey spinal cord produces patterned activity remarkably similar to what one would expect such activity to be in the intact swimming lamprey. Other experiments in cats also give evidence for a spinal CPG. If the spinal cord is disconnected from the brain, or even the brainstem, then as long as the cat's weight is supported by a sling, the cat can make typical walking movements.

A suggestion made by Grillner (1981) is that the total output pattern of the limb could also result from the *combined* activity of different burst generators. Each unit burst generator (unit CPG) is then assumed to produce the rhythmical activity by itself and to contain all elements required for the bursting. The actual neuronal mechanisms utilized, however, are unknown (Grillner, 1981).

It is clear that even though the locomotor patterns can be generated autonomously, afferents play a crucial role in modulating the broad features of the motor output (Hasan & Stuart, 1988). Motor patterns generated in the absence of afferent input are

quite labile. A pure open-loop control mechanism for the CPG seems not very likely. Deafferentiation experiments in cats reveal an EMG pattern that is more 'fragile': it can easily break down in certain sequences and subsequently become reinstated again (Grillner, 1981). Forssberg, Grillner and Rossignol (1975) showed that the reaction to a perturbation during walking in chronic spinal cats was strongly phase-dependent; identical tactile stimuli applied to the dorsum of the foot gave rise either to a marked flexion or a marked extension response depending entirely on the phase of the step cycle in which the stimulus occurs. This adjustment after a perturbation can be regarded as an indication for a closed loop component in the control of the CPG.

It can be concluded that the emergent picture of the neural control of the basic locomotor synergy is flexible organization of central pattern generators, providing an output pattern that may be modified through a complex organization of feedback systems acting on both motorneurons, premotorneurons and other CPGs (Grillner, 1981). Sensory or descending control systems can be held responsible for inducing the changes in gait (Cohen, 1988). From this point of view, the CPG is suggested to be placed in the middle of the closed loop/open loop continuum.

Development of leg movements in human newborns

It is of course not possible to experimentally isolate the centres of locomotor control in humans as has been done in quadrapeds. The only tools we have to ground our hypotheses on are EMG measurements and kinematic analysis of rhythmical patterns that can be observed.

Features of newborn stepping and infant kicking are highly compatible with the animal-based models for locomotion mentioned above. Like other vertebrates, bilaterally coordinated leg activity is evident long before the achievement of erect locomotion. Newborn infants in the supine position perform highly rhythmical, regularly alternating kicking movements. When infants are held upright, these alternations look remarkably like mature walking and have been called the neonatal 'step reflex'.

Thelen and coworkers (1981) analysed kicking movements in one month old infants and concluded that these movements were a developmental manifestation of a central locomotor program capable of generating spatially and temporally patterned movements of the leg. As cortical structures in the one month-old infants are very poorly developed, especially in the motor areas associated with the legs (Conel, 1941, in Thelen 1981), Thelen argues that it is likely that these human pattern generators are located lower in the CNS. Another important finding supporting this hypothesis is that anencephalic infants can perform patterns of infant stepping that are very similar to normal healthy newborns (Peiper, 1961). Unfortunately, the role of descending control systems cannot easily be evaluated, even when comparisons are made with anencephalic children. Without more evidence from other primates demonstrating evidence of intermediate patterns, it is difficult to know how to place these data in the present phylogenetic context (Cohen, 1988).

The most important observations that can be made in human infants concerning stepping and kicking movements are the following. Stepping movements can be observed immediately after birth. After the age of about two months, these movements can

no longer be elicited. The most widely accepted explanation for this phenomena is that maturing cortical centres inhibit a primitive stepping reflex, just as other neonatal reflexes such as the Moro, tonic neck, palmar and plantar grasp reflexes are suppressed as the motor tract develops (Peiper, 1961; Touwen, 1976).

Unlike erect stepping, newborn supine kicking does not disappear. Spontaneous kicking remains in the infant's repertoire througout the first 6 months of age. Thelen (1982) concluded that kicking and stepping are the same movements and that the clue to disappearance of stepping and increase of kicking might due to be in the consequences of the infant's posture rather than in some yet unknown central neural processes. There is no agreement among different authors about the observed changes in frequency of the kicking movements. Thelen (1979, 1982) concludes that the frequency gradually increases during the first six months of life and then declines with the onset of crawling and walking. Geerdink (1993) analysed kicking movements in fullterm infants and reported a decreasing frequency of occurrence with age. The above mentioned 'cortical inhibition theory' as an explanation for these observed changes have been shown to provide an impoverished account of the complexities of developmental change (Hopkins, Beek & Kalverboer, 1992). More recently, theorists argue that movement properties emerge from the physical or biodynamical characteristics of the skeletomuscular system (e.g., Lockman & Thelen, 1993). As Thelen (1984) argues, infants undergo dramatic changes in the size, composition and proportions of their bodies, and in the strength and tone of their muscles. If the control parameters are indeed such factors as mass, stiffness and inertia, these must also undergo striking developmental transformations. The relatively lean, poorly muscled leg of the newborn, with its dominant flexor tone and weak extensor development is an entirely different moving creature than the well-muscled, fat leg of the 6 month-old. These changes must be viewed in cencert with neurological maturation as essential contributions to movement outcomes. According to this 'biodynamic' approach, new experiments have been carried out to increase our understanding of movement control in infants through the analysis of intersegmental dynamics (Schneider, 1990, Ullrich, 1991). It was concluded that smooth trajectories of kicking movements in 3 month old fullterm infants resulted not only from the muscle torque which counteracted and complemented gravity, but also from motion dependent torques generated by movement of the linked segments.

Another striking feature in the development of kicking movements is the fact that the phase relation between the movements of the joints (inter and intra limb) become less rigid (Thelen, 1985; Geerdink, 1993). Thelen (1985) argues that maturation involves a fundamental shift in the timing relationship between antagonist pairs from an in phase activation to a predictable phase lag, with the acquisition of finer and more complex patterns of coordination. To explain these developmental changes, we suggest that the hypothetical CPG's are more influenced by external sources of information with increasing age emanating from higher centres and proprioceptive information. It is likely that *if* a CPG is more influenced by variable external information, this is reflected in more variable output. Thus with age, the CPG becomes less independent (see Figure 1).

Forssberg (1985) made comparable suggestions in the context of locomotion at

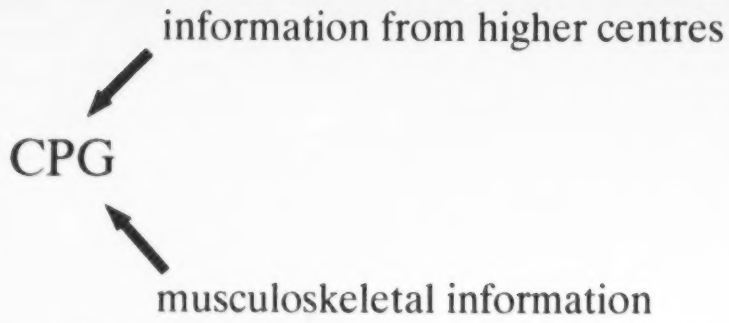


FIGURE 1 The central pattern generator influenced by external information.

later ages. He described the development of human bipedal locomotion from the first day of life until the first steps without external support about one year later. The main result was that infant stepping, supported locomotion and the first period of independent locomotion, lacked several of the functions that are specific to human plantigrade gait. Forssberg assumed a hierarchical system for human locomotor control similar to that of quadrupeds, but with additional neural mechanisms that transform the original pattern. An innate central pattern generator, initially programmed for non plantigrade gait, creates the basic infant stepping rhythm. Descending locomotor driving systems establish control during the first year and give the child the ability to control the locomotor activity. Forssberg concluded that man has a unique system which influences the central pattern generator and transforms the activity to the specific human plantigrade gait (Forssberg, 1985).

From hypothesis to research questions

The purpose of our research is to come to a better understanding of changes in the coordination of leg movements that can be observed in infants during the first year after birth. The two questions we address are:

1) Assuming that a spinal CPG exists, whas is the role of proprioceptive information in the development of this CPG?

2) What is the effect of changing physical characteristics of the musculoskeletal system on the development of spontaneous kicking movements?

The ultimate goal of this project is to formulate a simplest possible model of these components that yield a satisfactory description of the observable development.

In order to investigate the role of proprioceptive information, kinematic and electromyographic, data will be gathered during experimental manipulations in a longitudinal study with measurements at 6, 12, 18 and 24 wks of age. In order to evaluate the effect of changes in the external (gravitational) force field, two manipulations will be combined. On the one hand, the infant will be placed in the supine and upright positions; on the other hand, masses will be attached to the legs. To investigate the role of kinematic constraints on the activation of ipsi and contralateral leg muscles, the movements of one leg will be restricted. During all manipulations head position and behavioural state will be monitored.

As an 'experiment in nature', the same manipulations will be carried out on

infants with perinatal brain damage. In these subjects, it is likely that the supraspinal component develops abnormally. As it is expected that the spinal circuitry and the musculoskeletal system are unaffected in the first instance, it is hypothesised that the spontaneous kicking movements will not be much different from the movements of the fullterm at the youngest age. With age, the differences are hypothesised to become larger.

Besides gaining insight into fundamental principles concerning the development of leg coordination, the relevance of this study can be sought in two directions. In the first place, the results may be of diagnostic value in medical settings. In particular the data concerning the brain damaged children may have consequences for deriving intervention programmes. In the second place, our results may be useful in the field of robotics. Modelling a biological system that is able to make adaptations to perturbations is a typical problem in this field.

REFERENCES

Bernstein, N. (1967). *The coordination and regulation of movement*. London, Pergamon Press.

Brown, T. G. (1914). On the nature of the fundamental activity of the nervous centres: Together with an analysis of the conditioning of rhythmic activity in progression, and a theory of the evolution of function in the nervous system. *Journal of Physiology*, **48**, 19-46.

Cohen, A. H., & Wallèn, P. (1980). The neuronal correlate of locomotion in fish: "Fictive swimming" induced in an in vitro preperation of the lamprey spinal cord. *Experimental Brain Research*, **41**, 11-18.

Cohen, A. H. (1988). Evolution of the vertabrate central pattern generator for locomotion. In: A. H. Cohen, S. Rossignol & S. Grillner (Eds), *Neural control of rhythmic movements in vertebrates* (pp. 129-166). New York, NY: Wiley.

Forssberg, H. (1985). Ontogeny of human locomotor control I. Infant stepping, supported locomotion and transition to independent locomotion. *Experimental Brain Research*, **57**, 480-493.

Forssberg, H., Grillner, S., & Rossignol, S. (1975). Phase dependent reflex reversal during walking in chronic spinal cats. *Brain Research*, **85**, 103-107.

Geerdink, J. J. (1993). *Early motor development in preterm infants*. PhD thesis, Vrije Universiteit, Amsterdam.

Grillner, S. (1981). Control of locomotion in bipeds, tetrapods and fish. In: J. M. Brookhart & V. B. Mountcastle (Eds), *Handbook of physiology, section 1: The nervous system, volume II, part 2*. Baltimore: Waverly Press.

Hasan, Z., & Stuart, D. G. (1988). Animal solutions to problems of movement control: The role of proprioceptors. *Annual Review of Neuroscience*, **11**, 199-223.

Holst, E. von (1973). On the nature of order in the central nervous system. In: R. Martin (Ed), *The behavioral physiology of animals and man: the collected papers of Erich von Holst, Vol. 1*, (pp. 3-32). Coral Gables, FL: University of Miami Press.

Hopkins, B., Beek, P. J., & Kalverboer, A. F. (1992). Theoretical issues in the longitudinal study of motor development. In: A. F. Kalverboer, B. Hopkins & R. H. Geuze (Eds), *Motor development in early and later childhood: Longitudinal approaches*. Cambridge: Cambridge University Press.

Lockman, J. L., & Thelen, E. (1993). Developmental biodynamics: brain, body, behavior connections. *Child Development*, **64**, 953-959.

Meijer, O. G., Post, A. & Bongaardt, R. (1993). CPG or CIA. In: C. M. C. Bakker, M. A. M. Berger, C. A. M. Duorenbosch, C. E. Peper, M. E. T. Willems & F. T. J. M. Zaal (Eds), *Neural aspects*

of human movement : Implications for control and coordination. (pp. 76-94). Swtes & Zeitlinger B. V. : Amsterdam, Lisse.

Peiper, A. (1961). *Cerebral function in infancy and childhood*. New York : Consultants Bureau.

Schneider, K., Zernicke, R. F., Ulrich, B. D., Jensen, J. L. & Thelen, E. (1990). Understanding movement control in infants through the analysis of limb intersegmental dynamics. *Journal of Motor Behaviour*, **22**, 493-520.

Thelen, E. (1979). Rhythmical stereotypies in normal human infants. *Animal Behaviour*, **27**, 699-715.

Thelen, E., Bradshaw, G. & Ward, J. A. (1981). Spontaneous kicking in month-old infants : Manifestations of a human central locomotor program. *Behavioural and Neural Biology*, **32**, 45-53.

Thelen, E. & Fisher, D. M. (1982). Newborn stepping : an explanation for a 'disappearing' reflex. *Developmental Psychobiology*, **18** (**5**), 760-775.

Thelen, E. (1985). Developmental origins of motor coordination : leg movements in human infants. *Developmental Psychobiology*, **18** (**1**), 1-22.

Thelen, E. (1984). Learning to walk : Ecological demands and phylogenetic constraints. *Advances in Infancy Research*, **3**, 213-250.

Touwen, B. (1976). *Neurological development in infancy*, London : Spastics International and Heinemann

Ulrich, B. D., Jensen, J. L. & Thelen, E. (1991). Stability and variation in the development of infant stepping : implications for control. In : A. E. Patla (Ed.), *Adaptability of human gait*, Elsevier Science Publishers B. V. (North Holland).

Wiersma, C. A. G. & Ikeda, K. (1964). Interneurons commanding swimmeret movement in the crayfish, *Procambarus Clarkii* (Girard). *Comparative Biochemistry and Physiology*, **12**, 509-525.

THE ROLE OF STRENGTH IN THE DEVELOPMENT OF REACHING

Lia Out and G. J. P. Savelsbergh
Free University, Amsterdam

The aim of this study is to investigate whether muscle strength acts as a constraint during the development of reaching. An experiment is described in which reaching movements of infants at three, four and five months of age are registered (3D, 50 Hz) in three conditions: in supine, in sitting, and in sitting with weighted arms. Predictions concerning developmental changes in the kinematics and kinetics of the reaching movements are put forward.

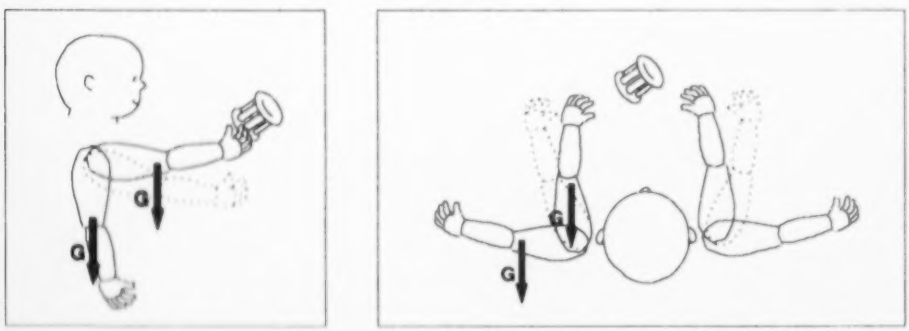
Introduction

This contribution concerns the development of arm movements in young infants. A planned experiment is described in which we aim to go beyond the mere description of what an infant does in attempting to reach for and grasp an object suspended in front of him. Our ambition is to explain some of the processes involved in this aspect of motor development.

When an adult reaches out for an object the hand moves in an almost straight path towards the object, with highly reproducible patterns of muscle contraction. This apparently simple action requires a complex interplay: sense organs pick up information about the distance and location of the object; the nervous system receives this information and somehow provides the right muscles at the right time with the right stimulus; and, once activated, these muscles produce the required forces. In the young infant each of these subsystems develops at its own pace. It is not surprising then, that infant limb movements continuously change in appearance, because they arise from interactions between these heterochronously developing subsystems. As a consequence, simple observation of infantile movement does not suffice for a complete understanding of motor development. A case in point is the work of Thelen & Fisher (1982) who showed that appropriate experimental manipulations can challenge widely accepted conclusions drawn from observation. Thus, they demonstrated that the disappearance of the stepping reflex in infants at four weeks of age could be explained by the disproportionably large amount of body fat during this period, resulting in legs being too heavy to lift against gravity. This programme of research provided the inspiration for the main goal of the experiment to be described here: to determine the influence of muscle strength on infant reaching movements between three and five months of age.

Acknowledgement: This research is carried out while the second author holds a fellowship from the Royal Netherlands Academy of Arts and Sciences.

The idea that strength can be a constraint on infant reaching is suggested by observations in our own lab, showing that children between three and five months of age reach longer and with a greater frequency for brightly coloured balls when supported in a sitting position than in supine (Savelsbergh & Van der Kamp, submitted). These findings may be explained by the situation-specific nature of generating strength, in that there are contrasting force requirements in sitting and supine, arising from differences in the orientation of the infant realtive to the force of gravity. Lifting an arm in order to reach requires a certain minimal force: muscles around the shoulder joint must generate torques large enough to overcome the torque that gravity imposes on the arm (see Figure 1). The torque to be overcome becomes larger when mass increases and when the moment arm (the distance between the centre of mass of the arm and the shoulder) increases, for torque is the product of force and moment arm and force that of mass and acceleration. On the other hand, the torque that the muscles can generate depends on their maximum force, that is, on the amount of muscle material in parallel, and on the muscle's moment arm with respect to the joint. All of these parameters are subject to change during development, and whether an infant's force suffices to lift the arm depends on their relative contributions: the ratio between fat tissue and muscle tissue can, for instance, be so high that the mass of the arm is too large with respect to the cross sectional area of the muscles. In addition, the ratio between length and circumference of the segments can be so high that the moment arm of the gravitational torque is too long relative to the muscles' cross sectional area. Maresh (1961) measured tissue shadows on roentgenograms (n=50), and showed that, between two and six months of age, the amount of fat tissue in the extremities increases much more rapidly than muscle tissue.



(a) (b)

FIGURE 1 Gravitational torque in sitting (a) and supine (b). Gravitational torque equals G (arm mass x 9.81 m s^{-2}) x moment arm (shortest distance to shoulder joint).

The hypothesis we want to test, stemming from the observed difference in reaching behaviour between sitting and supine, and knowledge about the changing morphology of the arm, is as follows: *During development, the relationship between the continuously changing arm composition and geometry can become such, that muscle strength acts as a constraint on reaching and systematically affects the kinematics of arm movements.*

Method

To test this hypothesis, we currently carry out an experiment in which detailed analyses are made of the reaching movements of ten full-term infants in combination with anthropometrical measurements of their arms. Recordings are made at three, four and five months of age, because previous research showed that infant reaching is particularly sensitive to the orientation of the infant within the field of gravity during this period (Savelsbergh & Van der Kamp, submitted). The infants are comfortably secured in a chair whose orientation can be adjusted around a frontal axis. They are then confronted for a few minutes with a brightly coloured toy rattle which is suspended, just out of reach, in the body midline at shoulder height. Three conditions are used, in which the orientation as well as the magnitude of the gravitational force are manipulated: in one condition the infant is supine with the backrest of the chair at 0° to the horizontal plane, in the second condition the infant sits at an angle of 90°, in the third condition the chair is also angled at 90°, but now 60 g. weights are attached to about the middle of the forearms. White markers (Ø 1.8 cm) are fixed on the shoulders, elbows and wrists, thus providing a marked contrast with the dark background. Movements of each arm are registered by two video cameras (Super-VHS, 50 Hz). The camera coordinates of the markers are automatically detected by VIDIPLUS, a computer programme written in MODULA-2. Three dimensional coordinates are reconstructed using the Direct Linear Transformation method (e.g., Dapena *et al.*, 1982). The three dimensional coordinates will be used to determine trajectories, velocities and accelerations, of the wrist, angles of the shoulder and elbow joints, angular velocities and accelerations, and joint torques. The determination of three dimensional joint torques by means of inverse dynamics (e.g., Hardt & Mann, 1980) requires knowledge of segment masses, positions of the segment centre of mass and moments of inertia. Schneider and Zernicke (1992) provide regression lines for estimating of these quantities based on the following data: body mass, length and circumferences of the upper and lower arms. Furthermore, skinfolds of upper and lower arm are measured, and will, in combination with the length and circumference data, be used to estimate composition of the arms.

Predictions

What predictions ensue from our hypothesis that a lack of strength may constrain reaching during development? When an infant's fat ratio is relatively high, or when the ratio length-circumference of the arm is relatively high, we expect that the infant will avoid high muscular torques in attempting to reach for the object. High torques can be avoided in several ways: on possibility is to bend the arm which decreases the gravitional moment arm and thereby the torque to be overcome; another possibility is to swing the arm towards the object. A rapid onset of muscular torques in the initial phase of the arm movement gives rise to high angular accelerations and thus to high inertial forces, which then diminish the required muscular torques that have to be generated during the rest of the movement. A lack of strength can also result in the hand not coming within the vicinity of the object. It is likely then that the maximum of the muscular torques produced is similar across conditions, and represents

the limits of the infant's possibilities. In particular the conditions with the chair at 90° with and without weights attached to the arms are comparable, in that the gravitational torque only differs in magnitude and not in orientation. A comparison with the 0° condition is harder to make because in this orientation different muscles are involved in producing a reaching movement.

An alternative hypothesis for explaining differences in reaching between the three conditions is to attribute them to a lack of control of muscular forces instead of a lack of muscular strength. In order to successfully control muscular forces, external forces such as the gravitational force have to be taken into account. When this process does not yet function properly, it is very likely that in situations in which the external forces differ either in magnitude or orientation, the appearance of movements will differ. It is, however, not easy to predict the features of a movement which is not optimally controlled, because even in a system that is considered to be optimally controlled, namely the adult, the criterion of optimality and the parameters to be controlled are as yet unknown. An additional experiment is planned that will assist us in deciding whether the infants are constrained by a lack of strength or by a lack of control when their reaching movements differ between the gravitational conditions. A similar experiment as described above will be carried out with adults, whose muscular control can be assumed to be at a high level. A lack of muscular strength will be simulated by loading their arm segments (with the chair at 0° and 90°) in such a way that the distribution and relative magnitude of the mass of the arms are comparable to those of the infant. Deviations from unloaded trials, both kinematically and kinetically, will be used to generate additional predictions based on our original hypothesis that strength may constrain reaching during development.

REFERENCES

Dapena, J., Harman, E. A. & Miller, J. A. (1982). Three dimensional cinematography with control object of unknown shape. *Journal of Biomechanics*, **15**, 11–19.

Hardt, D. E. & Mann, R. W. (1980). Technical note: A five body three dimensional dynamic analysis of walking. *Journal of Biomechanics*, **13**, 455–457.

Maresh, M. M. (1961). Bone, muscle and fat measurements: Longitudinal measurements of the bone, muscle and fat widths from roentgenograms of the extremities during the first six years of life. *Pediatrics*, **28**, 971–984.

Savelsbergh G. J. P. & Van der Kamp, J. The effect of gravity on infant reaching. *Journal of Experimental Child Psychology*, (submitted).

Schneider, K. & Zernicke, R. F. (1992). Mass, center of mass, and moment of inertia estimates for infant limb segments. *Journal of Biomechanics*, **25**, 145–148.

Thelen, E. & Fisher, D. M. (1982). Newborn stepping: An explanation for a "disappearing reflex". *Developmental Psychology*, **18**, 760–775.

ARE THERE PHASE TRANSITIONS IN THE DEVELOPMENT OF EYE-HAND COORDINATION?

R. H. Wimmers, G. J. P. Savelsbergh, P. J. Beek and B. Hopkins
Free University, Amsterdam

Our hypothesis is that developmental changes in eye-hand coordination (defined in terms of reaching and grasping objects) during the first six months of life carry the characteristics of a non-equilibrium phase shift. The presence of certain transition criteria such as sudden jumps, anomalous variance, bimodality and hysteresis can, at least in theory, demonstate that the changes in question have a dynamical basis.

A longitudinal study of one infant is reported in which we tried to identify stable developmental states of prehension during the first half year of life, as well as some of the transition criteria.

In using a dynamical approach, it is hoped that more insight will be gained into these states and the substitution of one state for another in motor development.

Key words: Development, infants, phase tansitions, eye-hand coordination.

Introduction

Over the last two decades, numerous physical, chemical, and biochemical systems have been shown to exhibit spontaneous transitions between different states or patterns of activity in response to changes in external conditions that are entirely unspecific as to the emerging pattern. These so-called phase transitions between macroscopically defined states have been described mathematically in terms of low dimensional dynamics (Haken, 1977; Thom, 1975; Prigogine, 1984). If a phase transition occurs in a system which is far from equilibrium, such as a moving animal, it is termed a non-equilibrium phase transition. During phase transitions of this type, fluctuations and nonlinearities play an essential role.

Motor development in early infancy has been characterized by phases, periods of little change sometimes referred to as stages or states, and phases of rapid change (Thelen & Ulrich, 1991). The mechanisms of developmental stability and change continue to be poorly understood. An initial step in tackling this problem is to ask whether the changes in question constitute non-equilibrium phase transitions. To do so requires an unambiguous definition of what is mean by a developmental transition.

Acknowledgments. This research was funded by the Netherlands Organization for Scientific Research (NWO), Grant No. 560-263-08, while the second author held a fellowship from the Royal Netherlands Academy of Arts and Sciences.

A developmental transition takes place when a *qualitative* change occurs from one macroscopically defined developmental state to another. At some critical point, the developmental state suddenly changes, for instance, from non reaching to reaching or from reaching without grasping to reaching with grasping. New developmental states can be viewed as stable attractors, which become available once the proper boundary conditions have been established. In that case, this new state frequently appears. Through establishing the stability of a developmental state by means of registering its frequency of occurence, changes between states can be distinguished and investigated.

The goal of this paper is to introduce certain transition criteria which, if detected, can prove that developmental changes belong to the class of non equilibrium transitions. The meaning of these criteria in relation to developmental transitions is discussed. Some of them are then illustrated by means of a longitudinal study of reaching and grasping in one baby.

Transition Criteria

Gilmore (1981) described eight criteria by which abrupt changes can be classified as discontinuous phase transitions (or catastrophes). He called these criteria 'catastrophe flags'. Five of them, namely, *bimodality*, *inaccessibility*, *sudden jumps*, *hysteresis* and *divergence*, appear simultaneously when a system is in transition. The other three, namely, *anomalous variance*, *critical slowing down* and *divergence of linear response* can be found prior to a transition, and therefore signal an upcoming transition.

Insights into the nature of these criteria can be gained by using a cusp model. A cusp model is one of the elementary catastrophes identified by Thom (1975), in which a transition is defined as a sudden change in a behavioural variable induced by a small and continuous change in an independent variable or control parameter. Although the control parameter is entirely unspecific as to the resulting pattern, its manipulation is instrumental in creating a new order at the macroscopic level. It controls in the sense of leading the system through its respective states of equilibrium.

Figure 1 shows different potential fields that belong to a potential function which can give rise to a cusp transition. By changing the control parameters of the potential function the minimum of the function changes as illustrated by the position of the black ball. The minima correspond with stable equilibrium states of the behavioural variable. Depending on the initial position of the behavioural variable, there are two possible pathways that can be followed, namely, from 1 to 7 and from A to C. Starting from 1, there is a change in the potential function when the control parameter on the x axis increases which results in 3, with a local maximum and a new local minimum. At 4, the two local minima are similar. If two minima are present at the same time, the potential function is said to process *bimodality*. The local maximum between the two minima gives rise to a region of *inaccessibility*. In increasing the control parameter along the x axis, we see that at 5 the original minimum reduces, that is the system cannot dwell there, and a new single minimum is established. At 6, the old minimum disappears and a *sudden jump* occurs to the remaining minimum. Going back from 7 to 1, the black ball will stay in the minimum until it disappears at 2; again a sudden jump occurs. The difference at which point a sudden jump occurrs as the control

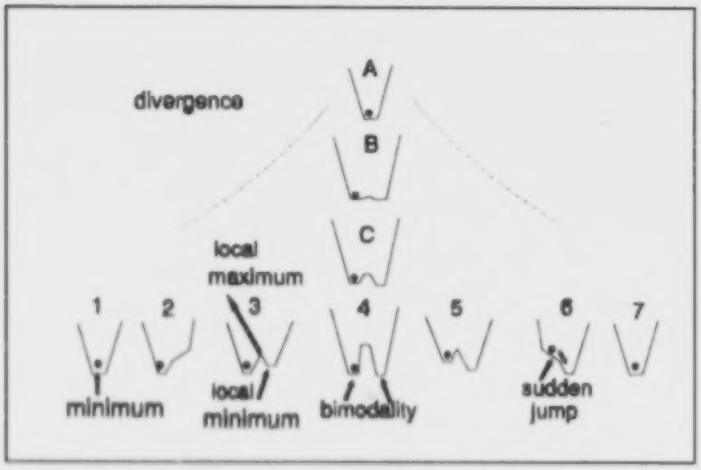


FIGURE 1 A potential landscape related to a cusp model. Different paths are possible, i.e. from A to C or from 1 to 7 or the reverse, depending on the initial starting positions and the direction of change of the relevant control variables.

parameter increases and decreases is called *hysteresis*.

Divergence takes place when two initial adjacent points diverge and result in two different states. When A constitutes the initial position and the variable on the y axis increases, the ball can terminate in the left or right minimum, each of which correspond to a different states.

A complex system's many subsystems act to a certain degree as stochastic forces which manifest themselves as fluctuations in the macroscopical state (Haken, 1977). The size of these fluctuations can be measured by means of the variance in the occurrence of a particular behaviour. The more stable the attractor is, the smaller will be its fluctuations. Close to the transition, the fluctuations should become particularly large until a transition has occurred. These large fluctuations are called *critical fluctuations*.

An emerging equilibrium can also be a source of fluctuations. These fluctuations can be measured by means of the amount of switching between states. Critical fluctuactions and oscillations between states belong to the *anomalous variance* criteria.

Due to a flattening of the potential function as the transition point is approached, the response of the system to external forces becomes weaker, a phenomenon called *critical slowing down*. If a small perturbation is applied to the system, which drives it away from its stationary state, the time it takes for the system to return to the perturbed state, the so called relaxation time, will be larger than when a stable state is perturbed. Hence, the relaxation time is a measure of the stability of the system.

The last catastrophe flag, *divergence of linear response*, is a consequence of a perturbation near a transition; it results in a larger loss of stability and large oscillations of the behavioural variable. Thus, the magnitude of the variance increased.

Exemplifying the Criteria

How can we translate or operationalize Gilmore's transition criteria in the context of developmental transitions?

In what follows, each of the above mentioned criteria will be further elucidated by means of specific examples.

1) *Bimodality.*

A necessary, but not sufficient requirement, for bimodality is that two qualitatively different behaviours are present. The requirement is not sufficient, because it should be possible to induce switching between the two behaviours (i.e. they should belong to the same behavioural dimension).

Bimodality within a person can be demonstrated by means of scaling the relevant control parameter(s) up and down. Two qualitatively different behaviours should be observed then.

By manipulating the control parameters, bimodal frequency distributions can be obtained.

2) *Inaccessibility.*

Inaccessibility is strongly related to the properties of bimodal score distributions. The middle part of the bimodal distribution is in principle also a particular behavioural mode, but because of its instability it is not accessible. However, by manipulating the proper control parameter(s) the inaccessible behavioral mode could stabilize again.

3) *Sudden jumps.*

Within a small range of time (as measured against the time scale of the behaviour), a qualitative change in the behaviour occurs while there is only a small change in the control parameter. In longitudinal data it is important to distinguish between a jump and an acceleration (Van der Maas & Molenaar, 1992). A jump occurs between two attractors, which correspond to two qualitatively different forms of behaviour. That is why this criterion is directly coupled to bimodality and inaccessibility. An acceleration implies a quantitative amplification of a particular type of behaviour. This might be due to an increase in strength of the underlying attractor.

4) *Hysteresis.*

To demonstrate hysteresis requires knowledge of changes in the values of the control parameter(s). Hysteresis only appears when the so called Delay convention is satisfied. This is the case when the system changes only as the old state becomes unstable. When, in contrast the system always seeks out the lowest potential minimum it is said to be governed by the a Maxwell convention. The system switches state before the old state actually becomes unstable. In these systems hysteresis does not occur.

In studying the development of reaching, the muscle/fat ratio of the arm can be viewed as a control parameter. When this ratio increases and decreases over time, one can expect to see a jump to a qualitatively new behaviour and a regression to the old one respectively. If the jump and the regression appear at different muscle/fat ratios, hysteresis has occured, but not if they appear at the same ratio. It should be clear then that regression itself is not synonymous with hysteresis. To firmly establish hysteresis, the changes in the control parameter(s) need to be known precisely.

5) *Divergence.*

This criterion is important for revealing the stability of the behaviour at different initial situations. If small changes in an experimental setup result in different behaviours, divergence has occurred. An important implication of this criterion is that it directs one to the role of different test conditions in inducing behavioural change.

6) *Critical fluctuations.*

Frequency distributions of the occurrence of the behavioural categories provide information about the relative stablility of the underlying attractive states. The frequency of occurrence is proportional to its local stability. Thus, changes in frequency of occurrence indicate changes in the stability of the behaviour, therefore can be used to detect the presence of this criterion. Changes between states can also inform us about the stability of the system. If, for instance, two attractor states exist and neither of them is strong enough to win, competition between them is to be expected. Fluctuations between the two behaviours can then be observed.

7) *Critical slowing down.*

An increase in relaxation time before a transition is only expected in systems obeying the Delay convention. Perturbing, for example, a reaching movement has normally little effect on the total movement time, but prior to a transition large effects may be observed.

8) *Divergence of linear response.*

Perturbation of the system close to a transition will enlarge the fluctuations within the present behaviour or the amount of switching between those behaviours present.

Applying the Criteria to Developmental Transitions: Some Preliminary Results

In the remainder of this paper, we discuss data obtained in a longitudinal study of one infant. The purpose of the study is twofold: to identify stable developmental states of prehension during the first six months of life, and to find evidence for one or more of the above mentioned criteria. One boy was observed weekly from 8 to 24 weeks. No observations were made at week 17 because the subject was ill.

The infant was seated in a purpose built chair, placed on a table at an angle of 70° to the horizontal plane. The seat and head supports could be adjusted in accordance with the size of the child. The baby was secured in the chair by belts.

A wooden dowel (14cm long and 5mm in diameter), with different colours, was presented to the baby. This object was attached to the tip of a black wooden rod 2.7 meters in length. A little bell was attached to the dowel to draw the infant's attention when necessary.

The sessions were videotaped with four cameras, two for each arm. Two cameras were placed above the infant's head, the other two being positioned obliquely left and right in front of the infant.

The dowel was presented at chest level along the midline section of the infant at a distance of about ¾ of his arm length. Four dowel orientations were presented randomly, namely, horizontal, vertical and 45° to the left and to the right. The total number of trials was dependent on the interest of the infant.

For the present purposes, video recordings were decoded into readily observable behavioural categories:

1) **non reaching**, in which the hand did not come within a range of 5cm of the object;
2) **reaching without grasping**, in which the hand came within a range of 5cm of the object or contacted it:
   a) the hand is *closed* during the reaching attempt;
   b) the hand is *open* during the reaching attempt;
3) **reaching with grasping**, in which the hand contact the object, and then grasped it.

Using these categories, we sought for exitence of transitions between them. As already mentioned, frequency distributions of occurrence of the behavioural categories provide information about the relative stability of the underlying attractor states.

The transition from non reaching to just reaching is shown in Figure 2. Not present at 8 weeks (session 1), reaching activity increases rapidly up to 12 weeks (session 5). In dynamical terms, this probably means that reaching has become a stable attractor. However at 16 weeks (session 9) a regression in the amount of occurrence of reaching occurred. It is probably due to the establishment of a new state, namely, grasping (see Figure 3).

The transition from reaching to that involving grasping is shown in Figure 3. At week 13 (session 6) grasping suddenly emerges. After that, a jump to a high grasping activity level occurs. A jump can be illustrated by means of a multiple regression analyses. We define two independent variables, one continuous and the other discontinuous, with a real jump between week 15 and 16 (session 8 and 9). We found that two variable together explains 84% of the data ($R^2 = .8433$). However, only the discontinuous variable has a significant (Beta continuous .0643, $p > .79$: Beta discontinuous .8640, $p < .05$) linear relation with the observed grasping data. The conclusion is that the

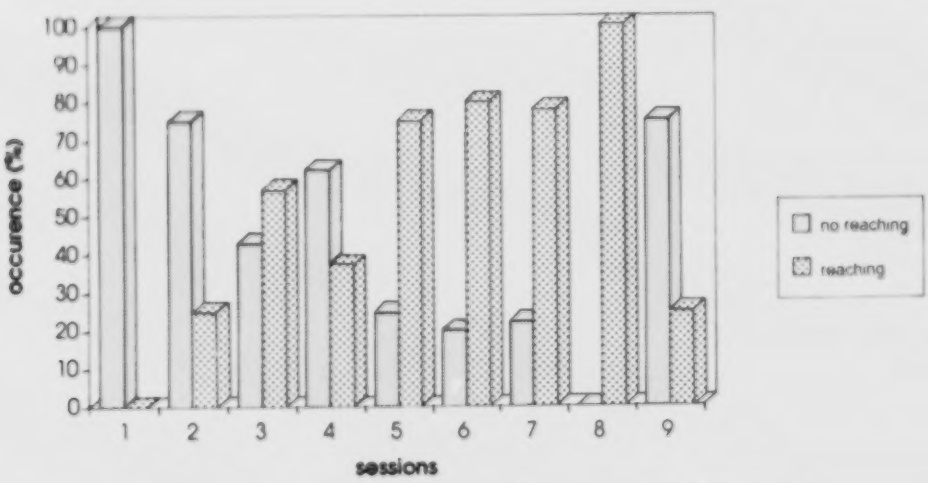


FIGURE 2 The emergence of reaching. The percentage of occurrences of non reaching and reaching from 8-16 weeks of life.

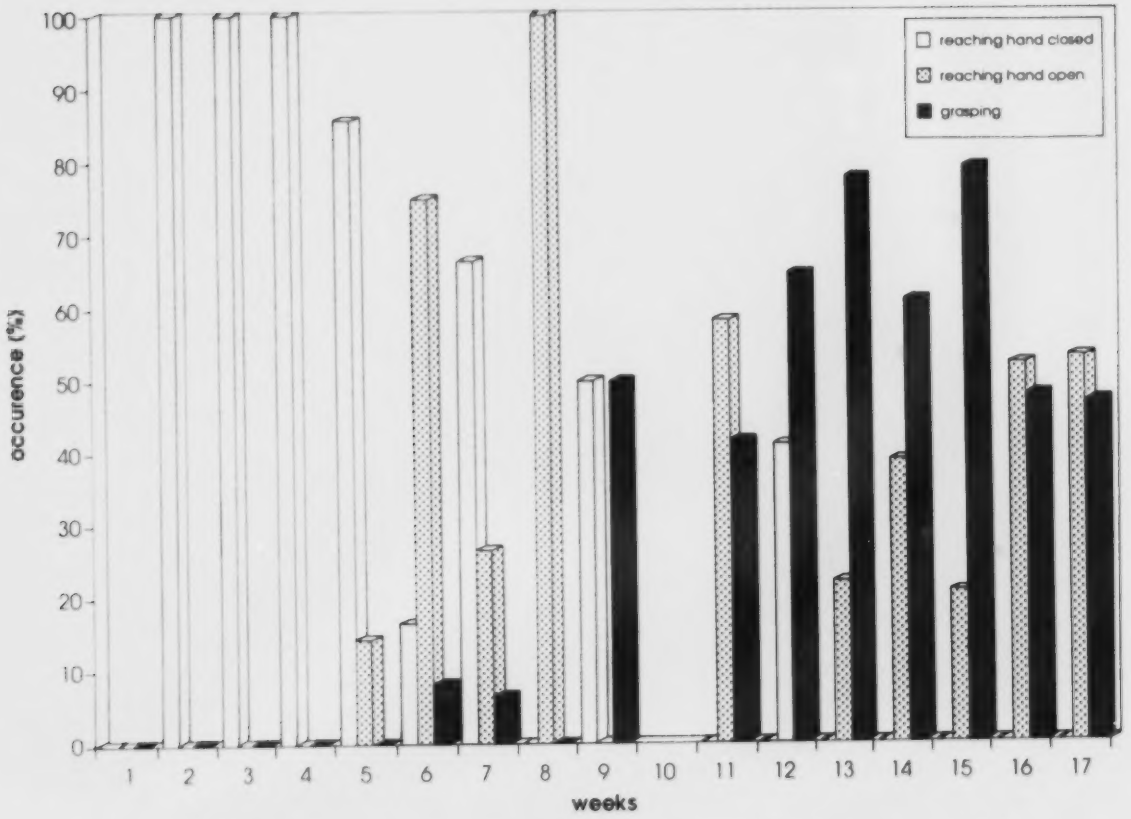


FIGURE 3 The emergence of grasping. The percentage of occurrence of reaching and grasping from 8-24 weeks. Competition between different states of prehension can be seen. Reaching with hand closed disappears and reaching with hand open and grasping emerges and then the states co-exist with each other.

emergence of grasping appears as a jump. Although reaching activity without grasping does not disappear, a qualitative change in reaching is evident, namely, reaching with the hand closed changes to reaching with the hand open (Figure 3). The existence of two states, reaching with and without grasping, can be seen as exemplifying the presence of bimodal.

Oscillations between states during a period of bimodality can be regarded as fluctuations. This probably means that both behaviours are competitive attractors, but neither of them is as yet strong enough to win. Another way of demonstrating fluctuations is to look at the variance of the occurrence of one particular category. Evidence for this sort of fluctuation can be seen in Figure 3 where the variance in the occurrence of reaching with the hand open is large from week 12 to week 16 (session 5 to 9), and established in week 18 to week 24 (session 11 to 17) with significant ($F(4) = 7.56$; $p < .05$) smaller fluctuations.

Discussion

Sudden jumps, bimodality and fluctuations are some of the criteria indicative of nonequilibrium phase shifts. Finding such 'fingerprints' of change provides preliminary confirmation of the hypothesis that the development of prehension during early infancy is based on non equilibrium transition between stable states of action. If replicated with more infants such finding may offer a substantial contribution to a general theory of developmental transitions based on dynamical principles.

Of course, the detection of such criteria in longitudinal data has to be confirmed by means of appropriate statistical analyses.

For the time being, the most pressing task is to discover the relevant control parameters which when scaled up beyond some critical value result in a discontinuous change of the behavioural state. As such, experimental manipulation of perception or action or both are required in and around the transitional ages identified by our longitudinal research.

REFERENCES

Gilmore, R. (1981). *Catastrophe Theory for Scientists and Engineers*. New York: Wiley.

Haken, H. (1977). *Synergetics: An Introduction*. Heidelberg: Springer.

Prigogine, I. & Stengers, I. (1984). *Order out of Chaos*. London: Bantane Books.

Maas, van der H. L. J. & Molenaar, P. C. M. (1992). Stagewise cognitive development: An application of catastrophe theory. *Psychological Review*, **99**, 395–417.

Thelen, E. & Ulrich, D. (1991). Hidden skills: A dynamic systems analysis of treadmill stepping during the first year. *Monographs of the Society for Research in Child Development*, Serial No. 223, Vol. 56.

Thom, R. (1975). *Structural Stability and Morphogenesis*. Reading, MA: Benjamin.

EXPLORING EXPLORATION IN THE DEVELOPMENT OF ACTION

John Van der Kamp and Geert J. P. Savelsbergh
Free University, Amsterdam

In this paper the role of exploration in the development of action is discussed from the perspective of the natural physical approach. It is argued that by means of repeated exploration of the perceptual motor work space, infants discover new couplings between information and movement; that is, new stable modes of action are acquired for a particular task. Furthermore, it is assumed that exploration is the behavioral equivalent of the fluctations that are indicators of transitions in movement actions. Exploration is assumed to be constrained by, and specific to, the transition at hand. Three exploratory search strategies (blind, local and non local) are discussed and illustrated with the example of infant reaching.

Keywords: Exploration, development of action, natural physical approach

Introduction

In this paper the role of exploration with respect to the development of action is discussed. This discussion partly reflects the growing awareness of the importance of exploration in the development of movement action (see, for example, the special issue of *Child Development*, 64, 1993). To assess the concept of exploration in the development of action, a short overview of the concept of exploration from the point of view of traditional drive and information processing approaches is presented first. Then, by combining the tools from non-linear dynamics with the ecological approach to perception and action, a natural physical approach (see Savelsbergh & Van der Kamp, this volume) of exploration is offered. In this approach exploration is regarded as a search of the perceptual-motor work space as result of which new couplings of perception and action are discovered. Furthermore, following Newell, Kugler, Van Emmerik & McDonald (1989), different search strategies are mentioned and illustrated by reaching in 3 to 6 month old infants.

The traditional view

The classic perspective asserts that exploration is instigated by organismic drives

Correspondence should be sent to Drs J. Van der Kamp, Faculty of Human Movement Sciences, Free University Amsterdam, Van der Boechhorststraat 9, 1081 BT, Amsterdam, The Netherlands.

(e.g. Nissen, 1954). To reduce primary drives like hunger, thirst, sex etc., the organism starts exploring until a consummatory response reduces the specific need. This terminates the exploratory activity. Through repetition of this sequence, the response is learned. It became clear, however, that various exploratory activities occurred in the absence of primary needs. In the famous study of Butler for example, monkeys learned to make discriminations in order to peek through a window, solely for the purpose of peeking. To accomodate these findings, alterations to the traditional scheme were suggested. Among others, a kind of independent exploratory drive was postulated which could be evoked by novel, complex or unfamiliar external objects or events (e.g. Montgommery, 1954).

Two decades later, cognitive approaches were predominant in psychology and exploration was considered to have a motivation inherent in information processing and action. Exploration was said to be instigated by an incongruence between a stimulus and a standard. An information conflict led to the modification or construction of the cognitive schemas and representations (e.g. Hunt, 1963; Nunnally & Lemond, 1973). Difficulties often arose, however, if one tried to differentiate between acquiring new skills and adapting a skill to slightly altered situations. Hence, it was unclear whether exploration should be confined to skill acquisition or if it should also involve adaptation to local circumstances. In short, within an information processing approach, exploration in relation to action was a poorly defined concept with no formal status. This paper seeks to find a more formal description of the role of exploration in the development of action.

A new view of exploration: A natural physical approach

Today, in the age of non-linear dynamics, the tools of catastrophe theory (and most recently complexity theory, see Levin, 1993) have become available to detect and describe qualitative changes or transitions. As a consequence, many studies concerned with the development of movement action are focusing on transitions (e.g. Goldfield, Kay & Warren, 1993; Thelen & Ulrich, 1991; Thelen, Corbetta, Kamm, Spencer, Schneider, & Zernicke 1993; Wimmers, Savelsbergh, Beek & Hopkins, this volume). Several indicators of the presence of transitional behaviour can be discriminated; Namely, hysteresis, enhanced fluctuations, critical slowing down (for a enumerative description of these criteria, see Wimmers et al., this volume). We would like to argue that, in relation to exploration, enhanced fluctuations are particularly interesting (see also Robertson, 1993; Turvey & Fitzpatrick, 1993). Enhanced fluctuations are reflected by larger variability or unpredictability in behaviour. These fluctuations enable the actor to discover or acquire new movement possibilities. In this sense, the concept of exploration is confined to the emergence of new skills (or stable modes) and does not involve adaptation or tuning to local circumstances. If fluctuations during transitions are the equivalent of exploratory activities, what picture emerges of the development of movement actions?

Although the nativist theories of researchers such as Gesell, McGraw and Shirley are not widely held anymore, the value of their descriptive studies is unquestioned. They described the development of action as a sequence of different motor milestones

such as reaching, grasping, crawling, creeping, sitting, walking etc. From the point of view of the natural physical approach (Savelsbergh & Van der Kamp, this volume), the emergence of these motor milestones is not just a consequence of the maturation of the nervous system, but a consequence of changing interaction between organismic *and* environmental constraints (Out & Savelsbergh, this volume). Important in this respect is the notion of the perceptual-motor workspace (Kugler & Turvey, 1987; Newell, Kugler, Van Emmerik & McDonald, 1989; Newell, McDonald & Kugler, 1991). The perceptual-motor workspace is regarded as;

> the dynamic interface between informational flows arising from perception and the kinetic flows arising from action. These fields are viewed as complementary in that not only can forces (kinetics) give rise to changes in flows (kinematics) but, in addition, flows can give rise to changes in the forces (Newell et al., 1991, p. 96).

The perceptual-motor workspace of the organism-environment interaction can be modelled as a 'layout' of gradient and equilibrium regions, i.e. as a field of interacting attractors. These attractors are defined over both physical and informational factors i.e. as a specific coupling between perception and action (Gibson, 1979). On a behavioural level, the attractors specify different stable modes of action (motor milestones). From this perspective, development is regarded as the transition from one stable mode of action to another (e.g. from reaching to grasping; see Wimmers et al., this volume). Stated differently, development is the emergence of new dynamical attractors (Kugler, Kelso & Turvey, 1982). The question that arises is how these new attractors or perception-action couplings are discovered. In other words, how are new stable modes of action acquired?

Discovering new perception-action couplings and acquiring new stable modes of action involve exploring and locating the gradient and equilibrium regions of the perceptual-motor workspace at hand. Exploration of the perceptual-motor workspace guides the organism to the discovery of new couplings between the informational and kinetic flows, thereby providing new stable modes of action (Goldfield et al., 1993; Kugler & Turvey, 1987; Newell et al., 1989, 1991; Savelsbergh & Van der Kamp, 1993, this volume; Thelen, 1990, Warren, 1990). Hence, development of action is achieved through exploration, i.e. by repeatedly producing (slightly) different movements or experimenting with different musculoskeletal organisations (cf. Goldfield et al., 1993) whereby the infant learns how to co ordinate and control his action system. The infant perceives information (proprioceptive, visual) produced by his/her movements and discovers how this information can be used to guide his/her movements. As argued above, this exploratory behaviour is especially prominent during transitions. This is nicely shown by Thelen in her earlier ethologically oriented studies (1979). She studied the occurrence of rhythmical behaviours like kicking, rocking, arm waving and banging in natural settings and showed that these behaviours occurred most frequently around transitions in movement actions. Rocking on hands and feet, for example, emerged in development just before the onset of crawling. This rocking presumably represents the

infant's exploration of his action capabilities and the (proprioceptive) information it produces. This eventually leads to a new stable mode of action (crawling). Through exploration of the perceptual-motor workspace the infant discovers how perception and action are coupled.

Exploration of the perceptual motor workspace (i.e. moving in it) both creates and annihilates equilibrium or gradient regions (Kugler & Turvey, 1987). Hence, the dynamical structure of the perceptual-motor workspace changes during exploration. This provides information which can be used to guide exploration (Newell et al. 1989, Gibson, 1988). In other words, exploration is not completely random but is constrained by, and specific to, the transition at hand. It is constrained because the exploration is dependent on the already acquired stable mode. Thelen et al. (1993) showed that the onset of reaching and grasping involves an increase or decrease of the initial muscle stiffness depending on the state of spontaneous movements before the onset of reaching. It is specific because exploration is directed toward one particular new stable mode of action, such as the rocking of hands and feet occurring only before the onset of crawling (Thelen, 1979).

Thus, exploration is constrained and specific. What about the instigation of exploratory behaviour? Bak & Chen (1991) argued that large interactive dynamical systems

> 'perpetually organise themselves to a critical state in which a minor event starts a chain reaction that can lead to a catastrophe (p. 26)'.

They termed this the theory of self-organised criticality. The action systems of humans with its many components (joints, muscles and nerves) might be such a large interactive system. If so, action systems evolve to fields where transitions from one stable mode of action to another stable mode of action are to be expected, i.e. to transitional regions. By this reasoning exploration can be considered as an inherent dynamical property of developing action systems, guiding the system to new stable modes of action. Intuitively and tentatively, this might also open new perspectives on intentionality in development.

If, as argued, exploration of the evolving perceptual-motor workspace is important in motor development and skill acquisition, a characterisation of such exploratory behaviour might help us to understand development. Following Gelfand & Tsetlin (1962), Newell et al. (1989) proposed three exploratory strategies: blind search, local search and non-local search. Blind search represents a strategy in which single equilibrium regions (attractors) are explored or located in a random or well-defined order without the use of memory characteristics. Local search, on the other hand, represents a continuous search of one equilibrium region or attractor space using knowledge from a previous search. A non-local search can be described as a non-continuous or intermittent search that is not confined to one equilibrium region or attractor. It enables a greater part of the workspace to be explored, often in conjunction with local search strategies.

To illustrate the above search strategies we will discuss some data from a recent

experiment (Savelsbergh & Van der Kamp, 1993, submitted). In this experiment, 3 to 6 month old infants seated in an infant chair were presented with a cardboard of nine red foam plastic balls (diameter 2.5cm). These balls were equally distributed in three rows and three columns. The balls were presented to the infants in three times for one minute each time. The number and duration of the reaches were scored. It was found that, in addition to one handed and two handed attempts an third type of coordination occurred. The younger infants (3 and 4 month olds) did not, but the older infants (5 and 6 month olds) did grasp the edge of the board with one hand, while reaching for the ball with the other hand. This strategy occurred only in the 5 and 6 months olds, that is, near the time of onset of a more stable form of reaching, grasping and catching (Von Hofsten, 1984). What is the significance of this particular behaviour in the older infants? One hypothesis is that, by grasping the board, infants become able to change the reaching distance. This enables the infants to explore the perceptual motor workspace for this reaching task in new ways. In other words, by varying the reaching distance, an optimal fit between infant and environment is actively being sought.

If this true, a different search strategy would be expected when the cardboard is grasped. To test this assumption, the nine balls in the reaching task were considered as attractors, and the balls which were successively grasped or contacted (Figure 1) was plotted.

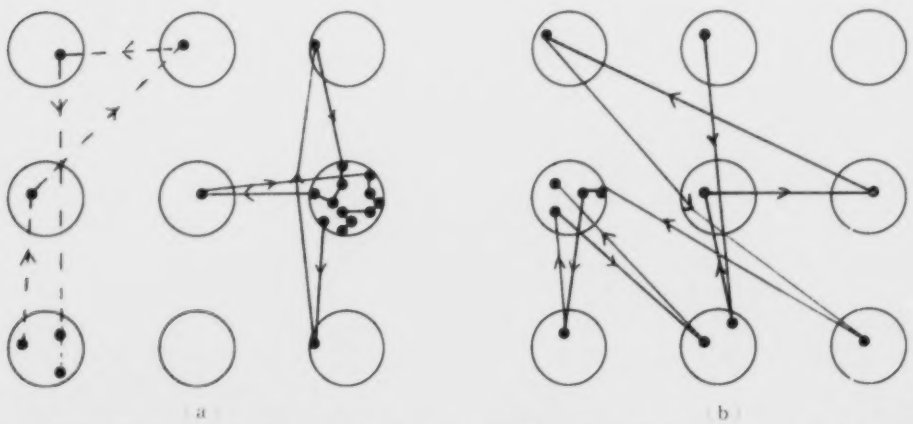


FIGURE 1 The distribution of the contacted and grasped balls. The left pannel shows a 24 weeks old infant not grasping the board, the right pannel shows the same infant grasping the board with the left hand (– – – left hand; —— right hand).

Differences in the distribution of contacted balls may indicate different search strategies. If contacts and grasps are concentrated around one ball, a local search strategy is assumed to be represented. If, on the other hand, contacts and grasps are distributed equally between several balls, a non-local or blind search strategy is assumed to be represented (it is difficult to distinguish blind and non-local search strat-

egies on basis of spatial distribution only*). Figure 1 (a) shows the distribution of contacted and grasped balls for a 24 week old infant for one minute when the board was grasped only once. In this situation, the right hand seems to represent a local search strategy; that is, the hand is predominantly directed to one ball. Figure 1 (b) shows the same infant for another minute. Now all contacts were made while the contra-lateral hand was grasping the edge of the cardboard. Here, the right hand is not directed to one particular ball, and shows a non local or blind search strategy. A tentative conclusion is that the emergence of grasping the board with one hand while reaching with the contra-lateral hand is accompanied by a change in search strategy, indicating that this behaviour may be regarded as a form of exploraton. In other words, when the cardboard comes within reach – as a consequence of growth of arm length – the dynamical layout of the perceptual-motor workspace changes, giving rise to a change in search strategy, which is specific for this task and the transition to reaching and grasping.

Conclusion

The natural physical approach, i.e. the ecological approach to perception and action using the tools of non-linear dynamics, offers a new point of view on exploration in the development of movement action. By means of repeated exploration of the perceptual-motor workspace, infants discover new couplings between information and movement. Hence, new stable modes of action are acquired for a particular task. It is assumed that exploration is inherent in the dynamics of large interactive dynamic systems and that exploration is reflected by the larger variability in behaviour in particular during transitions. Furthermore, exploration is thought to be constrained by, and specific to, a particular transition of one stable mode of action to the other.

REFERENCES

Bak, P., & Chen, K. (1991). Self organized criticality. *Scientific American, January*, 26-33.

Gibson, E. J. (1988). Exploratory behavior in the development of perceiving, acting, and the acquiring of knowledge. *Annual Review of Psychology*, **39**, 1-41.

Gibson, J. J. (1979/1986). *The ecological approach to visual perception*. Hillsdale: Lawrence Erlbaum.

Goldfield, E. C., Kay, B. A., & Warren, W. H. (1993). Infant bouncing: The assembly and tuning of action systems. *Child Development*, **64**, 1128-1142.

Hofsten, C. von (1984). Developmental changes in the organization of prereaching movements. *Developmental Psychology*, **20**, 378-388.

Hunt, J. McV. (1963). Motivation inherent in information processing and action. In O. J. Harvey (Ed.), *Motivation and social interactions: Cognitive determinants*. (pp. 35-94) New York: The Ronald Press Company.

Kugler, P. N., Kelso, J. A. S. & Turvey, M. T. (1982). On the control and coordination of naturally developing systems. In J. A. S. Kelso & J. E. Clark (Eds.), *The development of movement*

* Of course there are some problems in this strategy of analysing the data. Newell et al. (1991) for example, suggest that "it is the form of the search strategy through space (which could be guided by a general informational decision criterion) that is general, rather than the specific, output of the motor system" (p. 107). Moreover, in the experiment the number of 'attractors' change when a ball is removed from the board.

control and coordination (pp. 5–78). New York: Wiley.

Kugler, P. N., & Turvey, M. T. (1987). *Information, natural law, and the self-assembly of rhythmic movement: Theoretical and experimental investigations.* Hillsdale: Lawrence Erlbaum.

Levin, R. (1993). *Complexity: Life on the edge chaos.* London: Phoenix.

Montgommery, K. C. (1954). The role of the exploratory drive in learning. *Journal of Comparative Physiological Psychology, 47,* 60–64.

Newell, K. M., Kugler, P. N., Van Emmerik, R. E. A., & McDonald, P. V. (1989). Search strategies and the acquisition of coordination. In S. A. Wallace (Ed.), *Perspectives on the coordination of movement* (pp. 85–122). Amsterdam: North Holland.

Newell, K. M., McDonald, P. V., & Kugler, P. N. (1991). The perceptual motor workspace and the acquisition of skill. In J. Requin & G. E. Stelmach (Eds.), *Tutorials in motor neuroscience* (pp. 95–108). Dordrecht: Kluwer Academic Publishers.

Nissen, H. W. (1954). The nature of the drive as innate determinant of behavioral organization. In M. R. Jones (Ed.), *Nebraska Symposium on Motivation* (pp. 281–321). Lincoln: University of Nebraska Press.

Nunnally, J. C., & Lemond, L. C. (1973). Exploratory behavior and human development. In H. W. Reese (Ed.), *Advances in Child Development & Behavior, 8,* (pp. 59–101). New York: Academic Press.

Out, L., & Savelsbergh, G. J. P. (this volume). The role of strength in the development of reaching.

Robertson, S. S. (1993). Oscillation and complexity in early infant behavior. *Child Development, 64,* 1022–1035.

Savelsbergh, G. J. P., & Kamp, J. Van der (1993). The coordination of infant reaching, grasping, catching and posture: A natural physical approach. In G. J. P. Savelsbergh (Ed.), *The development of coordination in infancy* (pp. 289–317). Amsterdam: Elsevier Publishers.

Savelsbergh, G. J. P., & Kamp, J. Van der (this volume). A natural physical perspective on the development of infants eye–hand coordination: A search for the laws of control.

Savelsbergh, G. J. P., & Kamp, J. Van der (submitted). *The effects of gravity on infant reaching.*

Thelen, E. (1979). Rhythmical stereotypies in normal human infants. *Animal Behaviour, 27,* 699–715.

Thelen, E. (1990). Coupling perception and action in the development of skill: A dynamic approach. In H. Bloch & B. I. Bertenthal (Eds.), *Sensory motor organizations and development in infancy and early childhood* (pp. 39–55). Dordrecht: Kluwer Academic Publishers.

Thelen, E., Corbetta, D., Kamm, K., Spencer, J. P., Schneider, K., & Zernicke, R. F. (1993). The transition to reaching: Mapping intention and intrinsic dynamics. *Child Development, 64,* 1058–1098.

Thelen, E., & Ulrich, B. (1991). Hidden skills: A dynamic analysis of treadmill stepping during the first year. *Monographs of the Society for Research in Child Development, 56.*

Turvey, M. T., & Fitzpatrick, P. (1993). Commentary: Development of perception action systems and general principles of pattern formation. *Child Development, 64,* 1175–1190.

Warren, W. H. (1990). The perception action coupling. In H. Bloch & B. I. Bertenthal (Eds.), *Sensory motor organizations and development in infancy and early childhood* (pp. 23–38). Dordrecht: Kluwer Academic Publishers.

Wimmers, R. H., Savelsbergh, G. J. P., Beek, P. J., & Hopkins, B. (this volume). Are there phase transitions in the development of eye–hand coordination?

HOKUDAI "RCCCD" ROSTER

Name: Kunio Wakai
Title: Professor
Status at RCCCD: Director
Affiliation: Department of Developmental Psychology, Hokkaido Universtiy.
Research field: Developmental Psychology
Office No.: C 303, RCCCD
Office phone: 011-716-2111 (Ex. 3109)
Home address: 3-4-16 Nakajima cho, Eniwa 061-14
Home phone: (0123)34-5257
Education: M. Ed. 1964 University of Tokyo, Educational Psychology
B. A 1962 University of Tokyo, Educational Psychology
B. A 1959 Niigata University, Educational Psychology

Professional appointments:

1992 Invited Lecturer, Portland State University, Oregon, USA
1989 Professor & Director of the RCCCD, Hokkaido University
1982 Professor, Faculty of Education, Kobe University
1978 Associate Professor, Faculty of Education, Kobe University
1972-74 Visiting Scholar, Harvard Yenching Institute, Harvard University
1969 Assistant Professor, Faculty of Education, Hokkaido University
1967 Lecturer, Faculty of Education, Hokkaido University

Current research interests:

1. Cognitive development in early childhood.
2. Environmental affordance and children's play activity.
3. Development of sensori motor coordination in preschool children.
4. Experiential contexts of cognitive development; Mentors for contemporary Japanese college students.

Major publications & presentations: (In Japanese, if not otherwise noted)

Educational theories in the world: Jerome Kagan. *Educational Psychology*, 1979, 27, 10, 74-79.

Culture and cognitive development. In T. Muto (Ed.); *Advance of Piagetian psychology I: Language, society, and culture*. Tokyo, Kokudo sha Publ. Co., 1982.

Culture and Thought. Tokyo, Saiensu sha Publ. Co., 1982. (Translation of *Culture and Thought*, by M. Cole & S. Scribner. Wiley, 1974).

Textbook of developmental psychology. Tokyo, Seishin Shobo Publ. Co. (Translation of *Child Development and Personality*, by P. H. Mussen, J. Conger, & J. Kagan, Harper & Row, 1974).

"Ka Na'i Pono": A message from the Kamehameha Kingdom of child education. (In English). *Annual Report of the RCCCD*, 1984-85, 7, 63-70.

A note on the methodology of development research: The way how scientific knowing should be Lessons from "Cornell haox"—. *Bulletin of the Faculty of*

Education, Hokkaido University, 1991, 55, 145-155.

A quest for parental love: How do Japanese mothers conceive mothre's love? *Annual Report of the RCCCD*, 1990-91, 14, 97-117. (In English.)

Name: Shing-jen Chen
Title: Asssociate Professor
Status at RCCCD: Steering Committe Member & Research Fellow
Affiliation: Research & Clinical Center for Child Development
Research field: Behavioural Development
Office No.: C-308, RCCCD.
Office phone: Ext. 2607
Home address: 15-140 Higashi 2 chome, Kita 19 jo, Higashi-ku, Sapporo, 065
Home phone: 011-711-1231
Education:

D. Ed.	1990	Hokkaido University	Major: Developmental Psychology
M. Ed.	1978	Hiroshima University	Major: Pedology (Child Psychology)
B. Litt.	1975	Oxford University	Major: Social Anthropology
Diploma	1972	Oxford University	Major: Social Anthropology
B. L.	1968	National Cheng-chi Univ.	Major: Public Administration

Professional appointments:

1990 Associate Professor, RCCCD, Hokkaido University
1984 Assistant, Dept. of Developmental Psychology, Hokkaido University
1969-1971 Research Assistant Centre for Education in Public & Business Administration, National Cheng-chi University

Current research interests:

1. Dynamic systems approach to motor development (including cry expression).
2. Parenting, child-parent relationship in comparative perspective.
3. Vygotskian concepts and their application.

Major publications & presentations:

Chen, S. J. & Takahashi, Y. Cross-cultural comparison of mother-infant relationship in Japan and the United States: a critical review. *Japanese Psychological Review*, 31(1) 101-111, 1988. (In Japanese with English summary)

Chen, S. J. & Savelsbergh, G. J. P. Absence of avoidance response to impending collision in children. *Annual Report of the RCCCD*, Faculty of Education, Hokkaido University, 1991-1992, No. 15, 43-48.

Savelsbergh, G. J. P. & Chen, S. J. Looming: an information source for avoiding and making contact. *Annual Report of the RCCCD*, Faculty of Education, Hokkaido University, 1991-1992, No. 15, 49-54.

Chen, S. J. The microgenesis of graphic representation in children. *Annual Report of the RCCCD*, Faculty of Education, Hokkaido University, 1990-1991, No. 14, 63-71.

Chen, S. J. Child-rearing culture and modernization: Israel, China, and Japan. In Lamb, M. E., Sternberg, K. J., Hwang, C-P., & Broberg, A. g. (Eds.), *Child*

care in context : Cross cultural perspectives. 1992, 395-399, LEA, Hilsdale, N. J.

Name : Yukari Shirotani
Title : Instructor
Status at RCCCD : Full time staff
Affiliaion : Faculty of Education, Hokkaido University
Research field : Developmental psychology, Early childhood education
Office phone : 011-716-2111 (Ex. 3167)
Home address : 3-3-5-39-401, Hassamu, Nishi-ku, Sapporo 063
Education : M. A. 1989 Tsukuba University, Psychology
B. A. 1987 Tsukuba University, Psychology
Professional appointments :
1993 Counselor of child development, Hokkaido University Hospital
1991 Instructor, Hokkaido University
1990-1991 Counselor of child development, Health Center for Ibaraki Prefecture
1987-1991 Counselor of child development, Tsukuba Infant Consultation
Current research interest :
1) Cognitive development in childhood ; development of representation
2) Infant therapy and consultation
3) Child education
Major publications & presentations :
A developmental study of children's drawing : Drawings of cubes. Tsukuba Psychological Research, 1991, 13, 203-208. (In Japanese with English abstruct)
Perspective taking in children's drawing of balls. Annual Report of the RCCCD, 1990-1991, 14, 93-96. (In English)
The relations of young children's understanding of representational change, false belief, and the appearance-reality distinction. Tsukuba Psychological Research, 1990, 12, 145-150. (In Japanese with English abstact)
Effects of real experiences on cognitive development in preschool children. Tsukuba Psychological Research, 1990, 12, 137-144. (In Japasese with English abstract)
Young children's understanding of the appearance-reality and pretending-reality distinctions. Tsukuba Psychological Research, 1989, 11, 73-78. 12, 137-144. (In Japanese with English abstract)
On the play therapeutic process for a six year old stuttering child. Bulletin of Tsukuba Developmental and Clinical Psychology, 1992, 4, 43-49. (In Japanese)
A report of consultation for young children who have mental retardation and/or developmental disorders in Ibaraki prefecture. Bulletin of Tsukuba Developmental and Clinical Psychology, 1992, 4, 73-78. (In Japanese)

Name : Kimiharu Satoh
Title : Associate Professor

Status at RCCCD: Steering Committee Member and Research Fellow
Affiliation: Department of Develpm. Psychol., Fac. Ed., Hokkaido Univ.
Research field: Cognitive Development
Office No.: C-203, RCCCD
Office phone: 011-716-2111 (Ex. 3291)
Home address: 3-chome 4-3, Taihei 8-jo, Kita-ku, Sapporo 002
Home phone: 011-774-1387
Education: M. Ed. Hokkaido University, Developmental psychology
Professional appointments:

1989 Assistant Prof., Faculty of Education, Hokkaido Undversity
1982 Assistant Prof., Hokkaido University of Education, Iwamizawa
1979 Lecturer, Hokkaido University of Education, Iwamizawa
1978 Assistant, Hokkaido University of Education, Iwamizawa

Current research interests:

- Cognitive development in childhood.
- Children's discourse processes in literary learning.
- Social interaction and its effects on knowledge acquisition of children in classroom settings.
- Children's knowledge acquisition and learning precesses in science education.

Major publications & presentations:

A study on children's attention allocation and selective memory on incidental memory task. *Japanese Journal of Educational Psychology*, 1982, 30, 201-210. (In Japanese with English summary)

Reflection-impulsivity as a differentiation of a decision criterion under decision-making situation. *Japanese Journal of Educational Psychology*, 1983, 31, 186-194. (In Japanese with English summary)

A study on the development of communication behavior and of the knowledge of communication strategy. *Japanese Journal of Psychology*, 1984, 31, 303-306. (In Japanese with English summary)

Knowledge acquisition of children in science learning. *Bulletin of Hokkaido Uniuersity of Education*, 1987, 37, 101-115. (In Japanese).

A note on children's discourse comprehension in educational settings. I ~ III. *Bulletin of Hokkaido University of Education*, 1988~89, 38~39. (In Japanese).

Analyzing eye-fixations to asssess individual differences in solution strategies for spatial tasks. *Annual Report* 1990-1991, Research and Clinical Center for Child Development, Faculty of Education, Hokkaido University, 1992, 14, 81-91.

A social interactional perspective in development and learning (part 1), *Bulletin of the Faculty of Education*, Hokkaido University, 1992, 39, 23-44. (In Japanese).

Name: Takashi Morotomi
Title: Professor
Status at RCCCD: Steering Committee Member and Research Fellow
Research field: Cognitive clinical Psychophysiology, Perception

Office phone : 011-716-2111 (Ex. 3105)
Home address : 10-18, 2-chome, Asari, Otaru, 047-01
Education : M. Ed. 1968 Hokkaido Univesity, Psychophysiology
B. A 1965 Hokkaido University, Clinical Psychology
Professional appointments :
1991 Professor, Facuty of Education, Hokkaido University
1983 Professor, Faculty of Education, University of Iwate
1979-1981 Visiting Research Fellow, Univ. of Keele
1974 Associate professor, Faculty of Education, University of Iwate
1972 Lecturer, Faculty of Education, University of Iwate
1970 Assistant, Faculty of Education, University of Iwate
Current research interests
(1) Investigation of evoked potential correlates of depth and subjective contour.
(2) EEG and event-related potential study on habituation and dishabituation as basic mechanism of learning.
(3) Event-related potential study on memory representation of mental retardation by odd ball paradigm.
Major publication & presentations :
1. The effect of repetition of semantic priming task on event-related potential. *Japanese Journal of Physiological Psychology*, 1993, vol. 11 (In Japanese)
2. Visual evoked potentials elicited by subjective contour figures. *Scandinavian Journal of Psychology*, 1991, vol. 32.
3. Evoked potential correlates of Kanji processing ; the interaction between meaning and configuration. *Logopedics and Phoniatrics*, 1986.
4. Enhancement of visual evoked potentials occured in the recovery process. *Electroencephalography* and *Clinical Neurophysiology*, 1983, vol. 56
5. Selective reduction in visibility of a post-target by an identical pre-target masked by noise. *Perception & Psychophysics*, 1981, vol. 30
6. Enhancement of evoked responses to brief flashes and its correlation with off responses to pre-exposed light stimulation. *Vision Research*, 1975, vol. 15.

Name : Takashi Furutsuka
Title : Associate Professor
Status at RCCCD : Steering Committee Member and Research Fellow
Affiliation : Department of Special Educ. & Clinical Psychol., Fac. Ed., Hokkaido Univ.
Research field : Developmental disorders in cognition
Office No. : C-206, RCCCD
Office phone : 011-716-2111 (Ex. 3108)
Home address : 2-chome 9-2, 6-jo, Kita-ku, Sapporo 002
Home phone : 011-773-4898
Education : M. Ed Hokkaido University, Major : Psycho-physiology
B. Ed. Hokkaido University, Major : Perception and motion.

Professional appointments:

1985 Assistant Professor, Faculty of Education, Hokkaido University
1975 Assistant, Faculty of Education, Hokkaido University

Current research interests:

1. Cognitive development in children with mental and affective disorders.
2. Rearrangement of transactions in children with developmental disorders and their mothers.

Major publications & presentations:

Furutsuka, T. Effects of rapid attention switching on the N1-P2 amplitude of the visual event-related potentials. *Annual Report*, 1987-1988, (No. 11), RCCCD, Faculty of Education, Hokkaido University, 1988.

Furutsuka, T. Helping families with mentally handicapped children. *Hattatsu*, 1990, No. 11 (Supplement volume). (In Japanese).

Name: Jun'ichi Katayama
Title: Instructor
Status at RCCCD: Steering Committee Member and Research Fellow
Research field: Cognitive psychophysiology
Office phone: 011-716-2111 (Ex. 3089)
Home address: Kita 36, Higashi 19-3-26-B, Higashi-ku, Sapporo 065
Education: Ph. D. 1993 Kwansei Gakuin University, Psychology
M. A. 1986 Kwansei Gakuin University, Psychology
B. A. 1984 Kwansei Gakuin University, Psychology

Professional appointments:

1991 Instructor, Hokkaido University
1989-1991 Fellowship for Japanese Junior Scientists of the Japanese Society for the Promotion of Science

Current research interests:

Mechanisms of the human attentional processes.
Changes of event-related brain potentials associated with semantic priming effects.

Major publication & presentations:

Cognitive psychophysiology and event-related brain potentials. *Jinbun Ronkyu*, 1986, 36(3), 55-72. (In Japanese)

Sentence verification and event-related brain potentials. *Biological Psychology*, 1987, 25(2), 173-185.

Event related brain potentials to nonwords and semantically different words. *Perceptual & Motor Skills*, 1987, 65(3), 871-874.

A reply to Hillyard. *Perceptual & Motor Skills*, 1988, 66(2), 354.

The effects of saccade direction on saccade-related brain potentials. *Japanese Journal of Physiological Psychology and Psychophysiology*, 1989, 7(1), 53-58. (In Japanese with English abstract)

The effects of task relevancy on event-related brain potentials elicited by infrequently presented nonwords and semantically deviant words. *Psychologia*, 1990,

33(2), 91-99.

N400 in orthographic decision tasks. *Japanese Journal of Physiological Psychology and Psychophysiology*, 1990, 8(1), 39-45. (In Japanese with English abstract)

Negative brain potentials reflect the subjective distance between standard and deviant tones. *Biological Psychology*, 1990, 31(1), 95-100.

N400 during sentence verification task: Verification of historical statements. *Japanese Journal of Physiological Psychology and Psychophysiology*, 1992, 10(1), 15-22. (In Japanese with English abstract)

Negative brain potentials elicited by an unexpected color patch or word. *Electroencephalography and Clinical Neurophysiology*, 1992, 83(4), 248-253.

Name: Hajime Kobayashi
Title: Professor
Status at RCCCD: Steering Committee Member
Research field: Sociology of Education
Office No.: Faculty of Education Building
Office phone: 011-716-2111 (Ex. 3186)
Home address: Mogami, 1-19-6, 047 Otaru
Home phone: 0134-29-0784

Education: 1965 B. L. Hokkaido University

Professional appointments:

1991-Present Professor, Faculty of Education, Hokkaido University
1981-1990 Associate Professor, Faculty of Education, Hokkaido University
1980-1981 Professor, Faculty of Cultural Science, Sapporo Commercial Univ.
1978-1980 Assis. Prof., Faculty of Cultural Science, Sapporo Commercial Univ.
1972-1978 Lecturer, Faculty of Education, Hokkaido University.
1965-1972 Instructor, Hokkaido Fukagawa-Nishi High School.

Current research interests:

The relationship between endogeneous development of the area and educational reform of the adolescence in Japan, Italy, and Russia.

Major publications & presentations:

"Gle operai giapponsei alla catena" (Foudazione CESPE, Politica ed economia, AnnoXXI n. 3, 1990, Roma)

"Italia e Giappone: un confronto" (CISL, Il Progetto, Anno Xi n. 66, 1991, Roma)

"On the civic networks to bring up children's self enrichment" (Committee for the Joint Congress of Education in Hokkaido (eds.), *Hokkaido no Kyoiku*, 1991)

Dissimilation out of assimilation: life and culture of the workers in a big electric factory. (Report of the Centre for Industrial Education and Planning, Faculty of Education, Hokkaido University, n. 40, 1992)

Name: Tsutomu Suda
Title: Associate Professor
Status at RCCCD: Steering Comittee Member
Research field: Developmental Physiology
Office phone: 011-716-2111 (Ex. 5440)
Home address: Kita-40-jo, Higashi-9-chome, Higashi-ku, Sapporo 065
Education: B. A. 1966 Hokkaido University, Faculty of Education
Professional appointments:

1981 Associate Professor, Faculty of Education, Hokkaido University
1975 Lecturer, Faculty of Education, Hokkaido University
1973 Teacher, Naganuma Senior High School in Hokkaido
1967 Teacher, Bihoro Senior High School in Hokkaido

Current research interests:

1. Physical activity and fitness in elderly.
2. Development of physical fitness in children.

Major publication & presentations:

Suda T., et al. (1988) Retention of the fitness with aging after 31 to 33 years from the student days. *Japan J. Phys. Educ.* Vol. 32 No. 4: 255-265. (In Japanese with English summary)

Suda T., et al. (1990) Physiological responses to snow shoveling observed in aged men. In M. Kaneko (Ed.), Fitness for the Aged, Disabled, and Industrial Worker, *International Series on Sport Sciences* Vol. 20: 75-78, Human Kinetics Books

Suda T., et al. (1992) A study on the physical activities of the Chinese students: Difference of the physical activities in the daily lives between the Chin ese male students and the Japanese male students. *Japan J. Phys. Educ.* Vol. 36 No. 4: 359-370. (In Japanese with English summary)

Name: Katsuhiko Suda
Title: Professor
Status at RCCCD: Steering Committee Member and Research Fellow
Affiliation: Department of Educ. Methodology, Fac. of Educ., Hokkaido Univ.
Research field: Curriculum construction & educational methods
Office No.: Room #403, Faculty of Education, Hokkaido University
Office phone: 011-716-2111 (Ex. 3092)
Home address: 9-2-37 Kashiwaoka, Makomanai, Minami-ku, Sapporo 005
Home phone: 011-583-2270
Education:
Professional appointments:
Current research interests:

Curriculum construction of mathematics and science for secondary education.

Major publications & presentations:

The Archimedes' axiom from the viewpoint of mathematics teaching. (With K.

Yamaguchi) *Bulletin of the Faculty of Education, Hokkaido University*, 1987, 49, 25-42.

A study of system for teaching "function". (With K. Yamaguchi) *Bulletin of the Faculty of Education, Hokkaido University*, 1988, 50, 1-55.

Name: Michiko Seki
Title: Associate Professor
Status at RCCCD: Research Fellow
Affiliation: International Student Center, Hokkaido University
Research field: Early childhood education
Office phone: 011-716-2111 (Ex. 2650)
Home address: North 17 east 4, Higasi-ku, Sapporo, Japan
Home phone: 011-711-6269
Education: M. A. 1989 Wright State University Major: Education
B. A. 1973 Faculty of Education, Hokkaido University
Major: Developmental Psychology
B. A. 1971 Faculty of Literature, Hokkaido University
Major: English literature

Professional appointments:

1978 Assistant, RCCCD, Faculty of Education, Hokkaido University.
1974 Research Assistant, Bepartment of Developmental Psychology, Faculty of Education, Hokkaido Undversity

Current research interensts:

How young children read picture books and how they understand them. Literacy aquisition at home setting.

Major publications & presentations:

An ethnolgraphic study of process of response of a six year old to repeated readings of a picture book. Master's thesis submitted to Wright State University.

Name: Mamoru Gotoh
Title: Professor
Status at RCCCD: Research Fellow
Research field: Special Education
Office phone: 001-778-8811 (Ex. 336)
Home address: 7-5-5, Yamate-machi, Hirosima-cho, Sapporo-gun, Hokkaido
Education: M. Ed. 1970 Hokkaido University Major: Develpm. Psychol.
B. Ed. 1966 Hokkaido Univ. Educ. Major: Educational Psychology

Professional appointments:

1990 Director, Research Institute of Rural Education, Hokkaido University of Education
1983 Professor, Faculty of Education, Hokkaido Univ. of Educ., Sapporo
1976 Assoc. Prof, Faculty of Education, Hokkaido Univ. of Educ., Sapporo

1973 Assistant. Faculty of Education, Hokkaido Univ. of Educ., Sapporo

Corrent research interests:

1. Preschool education for handicapped children
2. Study on the behavior space analysis

Major publication & Presentations:

Methodological investigation on the behavior space analysis. *Bulletin of Hokkaido University of Education*, 1983, 34, 73-87. (In Japanese)

A study on systematization of behavior space Therapy. *Bulletin of Hokkaido University of Education*, 1984, 34, 77-86. (In Japanese)

Preliminary consideration on a validity of relative behavior coefficient. *Bulletin of Hokkaido University of Education*, 1992, 42, 147-156. (In Japanese)

A study on integrated education (II). Analysis of kindergartens in rural parts of Hokkaido. The Rural Education Institute, Hokkaido University of Education, 1993, 43-49. (In Japanese)

Name: Hiroshi Usui
Title: Associate Professor
Status at RCCCD: Research Fellow
Affiliation: Hokkaido University of Education, Sapporo
Research field: Developmental Psychology; Socialization
Office No.: 214 Hokkaido University of Education, Sapporo
Office phone: 001-778-8811 (Ex. 359)
Home address: Minami 1-10, Heiwa dori 12 chome, Shiroishi-ku, Sapporo 003
Home phone: 001-861-7042
Education: M. Ed. 1973 Hokkaido University Major: Develpm. Psychol.
B. Ed. 1971 Hokkaido Univ. Educ. Major: Social Psychology

Professional appointments:

1981 Assoc. Prof, Dept. Educ. Psychol., Hokkaido Univ. of Educ., Sapporo
1978 Assist. Prof, Dept. Educ. Psychol., Hokkaido Univ. of Educ., Sapporo
1976 Assistant. Prof, Dept. Educ. Psychol., Hokkaido Univ. of Educ., Sapporo

Currest research interests:

I am interested in the socializing processes of children in the school settings. Especially, my curiosity focuses on the social and cultural influences on the behavioral and motivational aspects of children's academic achievement. As well, I am also interested in the socialization in the family.

Major publications & presentations:

Evaluation of one's task performance in reflective and impulsive children: Analysis of metacognition. *Annual Report of RCCCD*, 1992, 73-79. (In English)

Psychological development in the preschool years, (with N. Uchida and H. Fujisaki), 1991, Yuhikaku. (In Japanese)

Cross-cultural differences in maternal control communications and child compliance: Japan and the U.S.A. (With D. Bradshaw et al.) In Bulock, M. (ed.) *Motivational and Interactive Processes*, Basel, 1991, pp. 55-68.

Name: Yasuji Kojima
Title: Professor
Status at RCCCD: Research Fellow
Affiliation: Hokkaigakuen University
Research field: Cognitive development
Office No.: C-201 Hokkaigakuen University
Office phone: 001-841-1161 (Ex. 593)
Home address: 332-485 Makomanai, Minami-ku, Sapporo 005
Home phone: 001-592-2604
Education: M. Ed. Hokkaido University Major: Developmental Psychology
B. Ed. Hokkaido Univ. Educ. Major: Educational Psychology

Professional appointments:

1992 Professor
1989 Assoc. Prof. Faculty of General Educ. Hokkaigakuen University
1985 Assist. Prof. Women's Junior College, Sapporo University
1983 Lecturer. Women's Junior College, Sapporo University

Current research interests:

My major concern is congnitive development in early childhood. Now I am particularly interested in the issues of story comprehension in children.

Major publications & presentations:

Developmental research: From the viewpoint of cognitive science. In J. Murai (Ed.) *Theory and methodology.* (New series of child psychology, Vol. 1, Kaneko-shobo, 1991. (In Japanese)

Theoretical perspectives on cognitive development: A new viewpoint to Piaget's theory. Seikyu-sha, 1987. (In Japanese)

Name: Shigeru Nakano
Title: Associate Professor
Status at RCCCD: Research Fellow
Affiliation: Department of Early Childhood Education, Fuji Women's College
Research Field: Developmental Psychology (Infancy & childhood)
Office Phone: 011-736-0311 (ext. 203), 011-736-2801, Fax: 011-709-8541
E-mail Address: nakano@abelab2.hubs.hokudai.ac.jp

Education:

Candidate for Ph. D., 1985, Graduate School of Education, Hokkaido University.
M. A. in Developmental Psychology, 1980, Graduate School of Education, Hokkaido University.
B. A. in Developmental Psychology, 1978, Faculty of Education, Hokkaido University.

Professional Appointment:

1988 Associate Professor of Developmental Psychology, Fuji Women's College.
1985 Assistant Professor of Developmental Psychology, Fuji Women's College.

Current Research Interests:

The goal of my recent researches is to investigate developmental processes of reading others' intention in children under age three. Especially, it is focused on whether they can read their mothers' play intention in teasing. In those research, referring Bateson's theory of meta-communication, relation between pretense and mindreading is being persisted.

Major Publications & Presentations:

The effects of mothers' teasing: Do Japanese infants read their mothers' play intention in teasing? *Early Development and Parenting*, Vol. 2 pp. 7-18, 1993.

Reconsideration of consistency of infant's attachment types classified by the Strange Situation Prodedure: From viewpoint of Japanese beliefs on "skinship." Paper presented at 7th Asian Workshop on Child and Adolescent Development. January, 1993, Jakarta, Indonesia.

Developmental changes in young children's understanding of their mothers' play intention during playful teasing. A paper prepared for a symposium at International Society for the Infant Studies in Paris, June, 1994.

Maternal playful teasing as a socializing device for toddlers' separation. A paper prepared for a symposium at International Society for the Study of Behavioral Development in Amsterdam, June, 1994.

Name: Yuko Kanaya
Title: Associate Professor
Status at RCCCD: Research Fellow
Affiliation: Department of Early Education, Kokugakuin College
Research field: Developmental psychology
Office No.: 204
Office phone: 3107
Home address: Stage 13 #505, N-13 W-4, Kita-ku, Sapporo 001
Home phone: 011-737-7002
Education: M. A. 1976 Keio University. Major: Developmental psychology
B. A. 1972 Tsuda College. Major: English literature

Professional appointments:

1988-Present Associate Professor, Department of Early Education, Kokugakuin College

1985-1988 Lecturer, Department of Early Education, Kokugakuin College

Current research interests:

My present research interest is in emotional development, particularly in issues such as the following; the function of emotion in human development, the differences and commonalities in socialization of emotion in different social network systems, the relations between the mode of infant-mother or infant-significant others' emotional communication and the later development of self regulation.

Major publications & presentations:

Kanaya, Y. (in press) The development of infant-mother attachment relationship

(in Japanese). *Journal of Developmental Psychology and Medicine.*

Kanaya, Y. et al. (1988) Cross-cultural study of expressive behaviour of mothers in response to their 5-month-old infants' different emotion expression. *Annual Report of the RCCCD*, 25-31.

Kanaya, Y. (1986) Are maternal emotions associated with infant temperament and attachment? *Annual Report of the RCCCD*, 51-58.

Kanaya, Y. & Miyake, K. (1985) The relation between mother-infant interactional characteristics in early infancy and later attachment as assessed in the Strange Situation. *Annual Report of the RCCCD*, 31-42.

Name: Yoshinobu Takahashi
Title: Lecturer
Status at RCCCD: Research Fellow
Research field: Developmental Psychology
Office phone: 011-611-2111 (Ex. 2835)
Office Fax: 011-613-7134
E mail: Yoshi@shs. sapmed. ac. jp
Home address: 41-108 Minami 2, Nangou Dori 20-chome, Shiroishi-ku, Sapporo
Education: M. Ed. 1985 Hokkaido University Major: Developm. Psychol.
B. Ed. 1982 Hokkaido University Major: Developm. Psychol.
Professional appointments:
1990 Lecturer, School of Health Sciences, Sapporo Medical University
Current resarch interests:
I am interseted in cognitive development, especially development of representational ability in preshooler.
Major publications:

Takahashi, Y. (1990) Separation distress of Japanese infants in the Strange Situation. *Annual Report*, 1988-1989, RCCCD, Faculty of Education, Hokkaido Uniersity, 141-150.

Takahashi, Y. (1989) Bellief about stability of personality characteristics in infancy and early childhood. *Annual Report*, 1987-1988, RCCCD, Faculty of Education, Hokkaido University, 49-54.

Takahashi, Y. (1987) Behavioral inhibition and social expression of 12-month-old infants. *Annual Report* 1986-1987, RCCCD, Faculty of Education, Hokkaido University, 61-65.

Takahashi, Y. (1986) Beliefs about malleability and desirability. *Annual Report* 1985-1986, RCCCD, Faculty of Education, Hokkaido University, p. 73-78.

Name: Emiko Kusanagi
Status at RCCCD: Graduate Student
Affiliation: Dept. of Developmental Psychology, Faculty of Educ., Hokkaido Univ.
Research field: Developmental Psychology

Office No.: C307, RCCCD
Office phone: 3106
Home address: 1-12-5, Kyoei-Machi, Hirosima-Cho, Sapporo-Gun, Hokkaido
Home phone: 011-372-3183
Education: M.A. 1991 Hokkaido University Major: Developmental Psychology
M.A. 1983 Nara Women's University Major: Biochemistry
B.S. 1981 Nara Women's University Major: Biochemistry
Professional appointments:
1991-present Lecturer (Part time), Eiyo Junior College
1991-present Counselor of child development, Sapporo Toyohira Health Center
1991-1992 Counselor of child development, Sapporo Minami Health Center
Current research interests:
My research interest is in the structure of temperament. I am also interested in the influence of temperamental individual differences on the development of cognition and personality.
Major publications & presentations:
Kusanagi, E. The structure of infant temperament: Emotional expression and the tendency to approach. *The Japanese Journal of Developmental Psychology*, 1993, Vol. 1, No. 4, 42-55. (In Japanese with English summary).
Kusanagi, E. A psychometric examination of the Children's Behavior Questionnaire. *Annual Report of the RCCCD*, Faculty of Education, Hokkaido University, 1991-1992, No. 15, 25-33.
Chen, S.J., Hoshi, N. & Kusanagi, E. Temperament and development in infancy. In Nihon Jido Kenkyu-jo (Ed.) *Advances in Child Psychology*, 1992, 31-57. Tokyo, Kaneko-shobo. (In Japanese).

Name: Nobuko Hosi
Status at RCCCD: Graduate Student
Affiliation: Dept. of Developmental Psychology, Faculty of Educ., Hokkaido Univ.
Research field: Developmental Psychology
Office No.: C307, RCCCD
Office phone: Ext. 3106
Home address: 4-3-350, Fujino, Minami-ku, Sapporo
Home phone: 011-855-8264
Education: B.A. 1986 Hokkaido University Major: Developmental Psychology
Professional appointment:
1989-Present Counselor of child development, Health Centers in Sapporo City
Current research interests:
Socio-emotional development of children, particularly temperamental individual differences from infancy. Now I am focusing on the structure of temperamental emotionality.

Name : Mika Iwata
Status at RCCCD : Graduate Student
Affiliation : Dept. of Developmental Psychology, Faculty of Educ., Hokkaido Univ.
Research field : Developmental Psychology
Office No. : C307, RCCCD
Office phone : 3106
Home address : 3-5-51 Maruyama Nishi machi, Chuo ku, Sapporo
Home phone : 011-612-6975
Education : M. A. 1990 Komazawa University Major : Family Sociology
B. A. 1986 Hosei University Major : Economics
Current research interests :

1. Child rearing stress and anxiety in mothers, maternal coping style with child rearing and their social network.
2. Maternal life style and life course.

Name : Eiko Kamada
Status at RCCCD : Graduate Student
Affiliation : Dept. of Developmental Psychology, Faculty of Educ., Hokkaido Univ.
Research field : Developmental Psychology
Office No. : C307, RCCCD
Office phone : 3106
Home address : 16-1-1-5-205, Kawazoe, Minami ku, Sapporo
Home phone : 011-572-6969
Education : B. A. 1993 Hokkaido University Major : Developmental Psychology
Professional appointment :

1993 Present Part-time advisor, Sapporo Kita Health Center.

Current research interests :

1. Processes of growing self acceptance in adolescents with negative self evaluation.
2. Developmental changes of child view and self concept in preschool education major students : A longitudinal comparison before and after the practice teaching.

執筆者紹介（掲載順）

稲垣佳世子（教授・千葉大学）
波多野誼余夫（教授・独協大学）
デボラ・シェッフェル（助教授・フォート・ヘース州立大学・アメリカ）
マレー・アルバート（教授・ニューヨーク大学）
松本敏治（助教授・室蘭工業大学）
吉塚孝（助教授・北海道大学）
ブライアン・ホプキンス（教授・アムステルダム自由大学・オランダ）
リチャルド・ヴァン・エマリック（研究員・アムステルダム自由大学附属病院・オランダ）
リチャルド・ワーヘンナル（専門研究員・アムステルダム自由大学附属病院・オランダ）
ルールット・サフェルスベルハ（専門研究員・オランダ王立科学アカデミー）
ジョン・ヴァン・デル・カンプ（アムステルダム自由大学・オランダ）
シュリエット・ファール（アムステルダム自由大学附属病院・オランダ）
カヌーク・ヴァン・ズウスト（フェロー・オランダ王立科学アカデミー）
リア・アウト（アムステルダム自由大学・オランダ）
レーモンド・ウィッマー（アムステルダム自由大学・オランダ）
ベータ・ベーク（アムステルダム自由大学・オランダ）

乳幼児発達臨床センター年報

第 16 号（1992 — 1993）

平成6年3月25日印刷　3月30日発行

編集発行者　若井邦夫

印刷所　興国印刷株式会社

発行所　北海道大学教育学部
附属乳幼児発達臨床センター
〒 060 札幌市北区北11条西7丁目
電話 011（716）2111 内線3109

ANNUAL REPORT
RESEARCH AND CLINICAL CENTER FOR CHILD DEVELOPMENT
No. 16（1992-1993）

Date of Print : March 25, 1994
Date of Publication : March 30, 1994
Editor : Kunio Wakai
Co-editor : Chen Shing jen
Printed : Kokoku Printing Co., Sapporo
Publisher : Research and Clinical Center for Child Development, Faculty of Education, Hokkaido University
Nishi 7, Kita 11, Kita-ku,
Sapporo 060 Japan